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Municipal Waste Combustion Assessment: Combustion Control at Existing Facilities

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Prepared By
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MUNICIPAL WASTE COMBUSTION ASSESSMENT: COMBUSTION CONTROL AT EXISTING FACILITIES

Prepared by
P.J. Schindler
Energy and Environmental Research Corporation
3622 Lyckan Parkway, Suite 5006
Durham, NC 27707

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EPA Project Officer: James D. Kilgroe
Air and Energy Engineering Research Laboratory
Research Triangle Park, NC 27711

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ABSTRACT

The EPA's Office of Air Quality Planning and Standards (OAQPS) is developing emission standards and guidelines for new and existing municipal waste combustors (MWCs) under the authority of Sections 111(b) and 111(d) of the Clean Air Act (CAA). The EPA's Office of Research and Development (ORD) is providing support in developing the technical basis for good combustion practice (GCP), which is included as a regulatory alternative in the standards and guidelines. This report provides the supporting data and rationale used to establish baseline emission levels for model plants that represent portions of the existing population of MWCs. The baseline emissions were developed using the existing MWC data base or, in cases where no data existed, engineering judgement. The baseline emissions represent performance levels against which the effectiveness and costs of emission control alternatives can be evaluated. An assessment of potential combustion retrofit options was developed and applied to each model plant, and emission reduction estimates were made for each retrofit application. This report provides the rationale used to estimate the emission reductions associated with each combustion retrofit.

FOREWORD

Based upon its analysis of Municipal Waste Combustors (MWCs), the Environmental Protection Agency (EPA) has determined that MWC emissions may reasonably be anticipated to contribute to the endangerment of public health and welfare and warrant further regulation. As a result, EPA's Office of Air Quality Planning and Standards is developing emission standards for new MWCs under Section 111(b) of the Clean Air Act (CAA) and guidelines for existing MWCs under Section 111(d) of the CAA.

In support of these regulatory development efforts, the Air and Energy Engineering Research Laboratory in EPA's Office of Research and Development has conducted an in-depth assessment of combustion control practices to minimize air emissions from MWCs. The results of this assessment are documented in the following reports:

Municipal Waste Combustion Assessment: Combustion Control at New Facilities, August 1989 (EPA-600/8-89-057)

Municipal Waste Combustion Assessment: Combustion Control at Existing Facilities, August 1989 (EPA-600/8-89-058)

Municipal Waste Combustion Assessment: Fossil Fuel Co-Firing, July 1989 (EPA-600/8-89-059)

Municipal Waste Combustion Assessment: Waste Co-Firing, July 1989 (EPA-600/8-89-060)

Municipal Waste Combustion Assessment: Fluidized Bed Combustion, July 1989 (EPA-600/8-89-061)

Municipal Waste Combustion Assessment: Medical Waste Combustion Practices at Municipal Waste Combustion Facilities, July 1989 (EPA-600/8-89-062)

Municipal Waste Combustion Assessment: Technical Basis for Good Combustion Practice, August 1989 (EPA-600/8-89-063)

Municipal Waste Combustion, Multi-Pollutant Study, Emission Test Report, Maine Energy Recovery Company, Refuse-Derived Fuel Facility, Biddeford, Maine, Volume I, Summary of Results, July 1989 (EPA-600/8-89-064a)

Municipal Waste Combustion, Multi-Pollutant Study, Emission Test Report, Mass Burn Refractory Incinerator, Montgomery County South, Ohio, Volume I, Summary of Results, August 1989 (EPA-600/8-89-065a)

The specific objectives of this document, "Municipal Waste Combustion Assessment: Combustion Control at Existing Facilities," are to present the data and supporting rationale used to establish baseline emission estimates for a set of MWC model plants, and to provide the rationale for estimating emission reductions that result from combustion retrofit alternatives developed for each model plant. The model plants represent various classes of MWCs that will be regulated by the Section 111(d) emission guidelines.

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1.0 SUMMARY

The EPA has completed a study which characterizes the emission performance of the existing population of municipal waste combustors (MWCs) and evaluates the technical feasibility and costs of applying retrofit controls to existing MWCs.[1] Twelve model plants were developed in this study which represent classes or groups of combustors in the existing MWC population that will be subject to the 111(d) guidelines. Baseline emission performance estimates were established for each of the model plants. A number of retrofit control alternatives, including combustion controls and various add-on controls, were applied to each model, and emission reduction and cost estimates were made for each control alternative. This report provides data and supporting rationale used to establish the baseline emission levels for each model plant and documents the basis for the estimated emission reductions associated with the application of combustion controls.

Table 1-1 presents design and operating data for the twelve 111(d) model plants, including combustor type, number of combustors per plant, unit size, total plant size, and heat recovery practices. Baseline emission levels were established for five air pollutants for each model:

- polychlorinated dibenzo-p-dioxin and dibenzofuran (CDD/CDF)
- carbon monoxide (CO)
- particulate matter (PM)
- hydrogen chloride (HCl)
- sulfur dioxide (SO_2)

Baseline emission levels are expressed as flue gas concentrations measured at the combustor or boiler outlet location, prior to treatment by add-on flue gas cleaning equipment. Unless otherwise noted, all emissions are normalized to 7 percent O_2. Table 1-2 summarizes the baseline emissions that were developed for each model plant, and Table 1-3 presents the estimated emission levels achieved with the application of good combustion controls.

Baseline emissions for all pollutants except acid gases (HCl and SO_2) were established using the available MWC emissions data base, or in cases where little or no data exist, engineering judgement. Emissions of HCl and SO_2 are dependent on waste feed characteristics. It was assumed that baseline

TABLE 1-1. 111(D) MODEL PLANTS

MODEL NO.	COMBUSTOR TYPE	UNIT SIZE tpd	UNIT SIZE Mg/day	# OF UNITS	TOTAL PLANT CAPACITY tpd	TOTAL PLANT CAPACITY Mg/day	HEAT RECOVERY
1	Mass burn refractory wall - traveling grate	375	341	2	750	682	No
2	Mass burn refractory wall - rocking grate	120	109	2	240	218	No
3	Mass burn refractory wall - split flow	300	273	3	900	818	No
4	Mass burn waterwall - large	750	682	3	2250	2045	Yes
5	Mass burn waterwall - midsize	360	327	3	1080	982	Yes
6	Mass burn waterwall - small	100	91	2	200	182	Yes
7	RDF spreader stoker - large	1000	909	2	2000	1818	Yes
8	RDF spreader stoker - small	300	273	2	600	545	Yes
9	Mass burn modular starved air - large	50	45	3	150	136	Yes
10	Mass burn modular starved air - small	25	23	2	50	45	No
11	Mass burn modular excess air	100	91	2	200	182	Yes
12	Mass burn rotary waterwall	250	227	2	500	455	Yes

TABLE 1-2. 111(D) BASELINE EMISSIONS

MODEL NO.	COMBUSTOR TYPE	CDD/CDF (ng/dscm)	CO (ppmv)	PM (mg/dscm)	HCl (ppmv)	SO2 (ppmv)
1	Mass burn refractory wall - traveling grate	4000	500	6900 (3 gr/dscf)	500	200
2	Mass burn refractory wall - rocking grate	4000	500	6900	500	200
3	Mass burn refractory wall - split flow	4000	500	6900	500	200
4	Mass burn waterwall - large	500	50	4600 (2 gr/dscf)	500	200
5	Mass burn waterwall - midsize	200	50	4600	500	200
6	Mass burn waterwall - small	2000	400	4600	500	200
7	RDF spreader stoker - large	2000	200	9200 (4 gr/dscf)	500	300
8	RDF spreader stoker - small	2000	200	9200	500	300
9	Mass burn modular starved air - large	400	100	345 (0.15 gr/dscf)	500	200
10	Mass burn modular starved air - small	400	100	345	500	200
11	Mass burn modular excess air	200	50	4600	500	200
12	Mass burn rotary waterwall	2000	100	4600	500	200

TABLE 1-3. 111(D) EMISSIONS RESULTING FROM COMBUSTION MODIFICATIONS

MODEL NO.	COMBUSTOR TYPE	CDD/CDF (ng/dscm)	CO (ppmv)	PM (mg/dscm)	HCl (ppmv)	SO_2 (ppmv)
1	Mass burn refractory wall - traveling grate	500	150	6900 (3 gr/dscf)	500	200
2	Mass burn refractory wall - rocking grate	500	150	6900	500	200
3	Mass burn refractory wall - split flow	500	150	6900	500	200
4	Mass burn waterwall - large	500	50	4600 (2 gr/dscf)	500	200
5	Mass burn waterwall - midsize	200	50	4600	500	200
6	Mass burn waterwall - small	200	50	4600	500	200
7	RDF spreader stoker - large	1000	150	9200 (4 gr/dscf)	500	300
8	RDF spreader stoker - small	1000	150	9200	500	300
9	Mass burn modular starved air - large	400	100	345 (0.15 gr/dscf)	500	200
10	Mass burn modular starved air - small	400	100	345	500	200
11	Mass burn modular excess air	200	50	4600	500	200
12	Mass burn rotary waterwall	400	100	4600	500	200

HCl and SO_2 emissions, when expressed on a concentration basis, are identical for combustors burning a given waste type. Two model plants, both refuse-derived-fuel (RDF) spreader stokers, burn processed waste. All other model plants burn raw, unprocessed municipal solid waste (MSW). Waste ultimate analyses are included for both fuels in the 111(d) technical support document.[1]

The goals of this report are to present the data and supporting rationale used to establish the emission concentrations in Tables 1-2 and 1-3. Section 2 provides background information describing the approach used in the model plant study, and Section 3 provides the rationale and data used to establish the baseline emissions and emission reduction estimates for each model plant.

2.0 BACKGROUND

On July 7, 1987, EPA published an Advance Notice of Proposed Rulemaking (ANPR) which announced EPA's intent to develop new source performance standards (NSPS) for new MWCs, and emission guidelines for existing MWCs under the authority of Section 111(d) of the Clean Air Act.[2] All plants that commence construction after the proposal date will be subject to the NSPS and all plants not subject to the NSPS are regulated by the guidelines. Section 111(d) requires that States submit plans to EPA describing the regulatory approach that will be implemented at existing facilities to ensure compliance with the guidelines. The plans are reviewed and approved by EPA and are implemented by the States.

Prior to the regulatory decision in July 1987, the majority of EPA's data gathering efforts were focused on the performance of new MWCs. It was determined that additional data were needed to assess the emission performance of existing MWCs and to provide guidance for retrofit applications. As a result, EPA developed and funded a study intended to:

1) Estimate baseline emission levels for model plants representing various groups of MWCs in the existing population.
2) Develop retrofit alternatives to reduce baseline emissions.
3) Estimate emission reductions associated with each retrofit alternative.
4) Develop cost estimates for each retrofit alternative.

The retrofit alternatives that were evaluated include modifications to the combustion process and retrofit of flue gas cleaning equipment. This memorandum documents the rationale for the model plant baseline emission estimates and the estimated emission reductions resulting from the application of combustion retrofits. A separate report has been developed to address performance levels associated with add-on controls.[3]

The background information that led to the MWC regulatory decision was compiled and published in a Report to Congress.[4] As part of this effort, preliminary recommendations were made defining good combustion practices for new mass burn waterwall, modular starved air, and refuse-derived-fuel (RDF) fired MWCs.[5] Good combustion practices are expected to minimize emission of organics from MWC systems. The original recommendations included three elements:

- Design
- Operation/Control
- Verification

The requirements to satisfy these elements are:

- MWCs must be designed in a manner that minimizes air emissions.

- MWCs must be operated within an envelope dictated by the design of the combustion system, and controls must be in place to prevent operation outside of the established operating envelope.

- The performance of the combustion system must be verified by way of compliance testing and through continuous monitoring of key design and operating parameters, such as combustion air flows, gas temperatures, CO flue gas concentrations, and O_2 flue gas concentrations.

The good combustion recommendations were developed primarily to provide a set of criteria against which the performance of new MWCs could be evaluated. However, the recommendations can also be used to evaluate the performance of existing MWCs by identifying design and operating features which could potentially be modified to improve emissions performance. The revised recommendations for good combustion practices used in this report are presented in Table 2-1. The revised recommendations are similar to those provided in the Report to Congress, with the exception of changes in some of the CO emission limits and the addition of a recommendation on PM control device temperature to address low temperature formation of CDD/CDF.

The good combustion practices defined in this report are designed to: (1) maximize in-furnace destruction of organic compounds, and (2) minimize conditions that lead to low temperature formation of CDD/CDF. Conditions within the combustion process that satisfy the first goal include:

- Mixing of fuel and air to minimize the existence of long-lived, fuel-rich pockets of combustion products.

TABLE 2-1. GOOD COMBUSTION PRACTICES FOR MINIMIZING TRACE ORGANIC EMISSIONS FROM MUNICIPAL WASTE COMBUSTORS

DESIGN	
Temperature at fully mixed height	1800°F (982°C)
Underfire air control	At least 4 separately adjustable plenums. One each under the drying and burnout zones and at least two separately adjustable plenums under the burning zone (MB/WW). As required to provide uniform bed burning stoichiometry (RDF)
Overfire air capacity (not an operating requirement)	40% of total air (MB/WW, RDF) 80% of total air (MOD/SA)
Overfire air injector design	That required for penetration and coverage of furnace cross-section
Auxiliary fuel capacity	That required to meet start-up temperature and 1800°F (982°C) criteria under part-load conditions
Downstream flue gas temperature	<450°F (<232°C) at PM control device inlet
OPERATION/CONTROL	
Excess air	6-12% oxygen in flue gas (dry basis) (MB/WW and MOD/SA). 3-9% oxygen in flue gas (dry basis) (RDF)
Turndown restrictions	80-110% of design - lower limit may be extended with verification tests
Start-up procedures	On auxiliary fuel to design temperature
Use of auxiliary fuel	On prolonged high CO or low furnace temperature
VERIFICATION	
Oxygen in flue gas	Monitor
CO in flue gas	Monitor - 50 ppm on 4 hour average, corrected to 7% O_2 (MB/WW and MOD/SA). 100 ppm at 7% O_2 (RDF)
Furnace temperature	Monitor - minimum of 1800°F (982°C) (mean) at fully mixed height across furnace
Adequate air distribution	Verification Tests
Downstream flue gas temperature	Monitor - <450°F (<232°C) at PM control device inlet

MB/WW - mass burn waterwall MOD/SA - modular starved air

- Attainment of sufficiently high temperatures in the presence of oxygen for the destruction of hydrocarbon species.

- Prevention of quench zones or low temperature pathways that will allow partially reacted fuel (solid or gaseous) to exit the combustion chamber.

All of these conditions are interrelated; successful destruction of trace organic species requires that all three conditions be satisfied in the MWC system. Mixing is not sufficient unless it is achieved at temperatures that assure thermal destruction of organic compounds. Completion of the mixing process at adequate destruction temperatures prevents escape of combustibles through low temperature pathways. Despite the continuing advancements made in combustion control, perfect mixing will never be achieved in a combustion system, whether conventional or waste fired. As a result, zero organic emissions will not occur. The goal of good combustion practice is to provide the conditions that will minimize air emissions of concern.

One important component which was not explicitly included in the original GCP recommendations addresses the potential for low temperature formation of CDD/CDF. These formation phenomena have been measured at several full scale MWCs, including the Prince Edward Island; Pittsfield, MA; North Andover, MA; and Pinellas County, FL, facilities.[6,7,8,9] Further discussion of test data from these plants is included in Section 3.0 of this report.

The discovery of CDD/CDF formation in full scale MWCs has prompted research in the laboratory to identify the parameters controlling low temperature CDD/CDF formation reactions. Bench scale experiments indicate that, under excess air conditions, CDD/CDF formation occurs on the surface of fly ash at temperatures ranging from approximately 200 to 400°C (392 to 752°F), with the maximum formation occurring near 300°C (572°F).[10] Conversely, research results have indicated that when the same experiments were performed in an oxygen-deficient atmosphere, dechlorination of CDD/CDF compounds occurred.[11] The current thinking regarding these findings is that the formation process may involve catalytic reactions of organic precursor compounds with particulates containing metallic species such as copper chloride ($CuCl_2$). The bench scale studies indicate that the rate of CDD/CDF formation and/or chlorination is affected by a number of parameters; including temperature, residence time, catalyst effects, carbon content, oxygen concentration, and moisture. Results from these experiments provide information which can be transferred to full scale MWCs in order to develop control strategies for minimizing CDD/CDF formation.

Although many strategies for minimizing the reactions (i.e., catalyst poisons) remain to be investigated, it appears at this time that an initial control strategy is to minimize the particulate matter concentration and the flue gas residence time at temperatures were the rate of CDD/CDF formation is highest. If organic precursor materials leaving the combustor are minimized and if flue gas retention times and PM concentrations can be minimized in the 200 to 400°C (392 to 752°F) temperature range, it appears that the formation process can be minimized. Many existing MWCs currently operate flue gas cleaning equipment (ESPs) in this temperature window. The increased gas residence time and PM concentrations which occur in the ESP may be the primary cause of CDD/CDF formation, leading to increased emissions in the stack. Recent data from a full scale MWC confirm that high efficiency ESPs operating at temperatures below 250°C actually provide significant CDD/CDF removal.[12] Based on these considerations, a new component of the good combustion practices was developed. The recommendation is to maintain PM control device inlet gas temperatures below 232°C (450°F).

As part of an information gathering effort in the MWC Retrofit Study, site visits were made to 12 MWCs that were judged to be representative of the major combustor classes in the existing population. Additional emissions data and design and operating information obtained through information requests were also used to characterize the performance of the existing MWC population. After review of all available information was completed, model plant configurations and baseline emission performance estimates were established.

The design, operation/control, and monitoring features of each model plant were evaluated relative to the good combustion practice recommendations. If emission levels for a model plant were relatively low, verification measures were in place, and the potential for reducing emissions through additional combustion modifications was questionable, then good combustion practices were judged to be in place for the model plant. If these criteria were not met, then additional evaluation of design and operating practices was required, and modifications were prescribed to correct any design and/or operating deficiencies. In a few cases, the modifications required only the addition of verification measures (e.g., CO monitors) to satisfy the good combustion practice recommendations.

Several model plants required more extensive analysis. In these cases, the following types of questions were raised regarding model performance:

- Is the system designed and operated to meet the required furnace temperature at the fully mixed location? What design and operating constraints prevent attainment of the required temperature?

- Are the waste feed system and underfire (primary) air control adequate to provide uniform stoichiometries in the primary combustion zone? What design and operating features prevent this?

- Is the overfire (secondary) air system designed with adequate capacity to achieve the proper penetration and coverage to ensure good mixing? Do variations in operating conditions (e.g. low load) result in changes to overfire air that cause the system to lose penetration and coverage?

- Is auxiliary fuel firing capacity available for use during start-up, shutdown and off spec (low temperature, high CO) operating conditions?

- Are combustor/boiler exhaust gas temperatures sufficiently low to minimize the potential for CDD/CDF formation in flue gas cleaning equipment?

- Is the unit operated with an acceptable excess air range that is sufficiently high to provide adequate oxygen to prevent fuel-rich conditions, yet low enough to prevent quenching of the combustion reactions?

- Are design and operating conditions adequate to prevent operational problems such as excessive corrosion, slagging, fouling, or poor waste volume reduction?

Are combustion control measures in place to ensure that the system is operated within the design envelope?

Retrofit approaches were developed for the models where design, operation/control, and/or verification deficiencies were identified. Each retrofit was site-specific, involving addition or modification of existing equipment or operating procedures, and in some cases, a virtual redesign and rebuild of the entire combustor. The recommended approaches were based on past experiences at existing plants, and in some cases, on engineering judgment. As each modification was developed, the effects on all other parts of the combustion system were evaluated to ensure that the various modifications were compatible, and that retrofits were not likely to result in operational complications.

The final two steps in the study were to develop cost estimates and emission reductions for each model plant. Cost development is described in a separate memorandum.[13] The rationale for estimating emission reductions is provided in the following sections of this report.

3.0 MODEL PLANT PERFORMANCE ESTIMATES

The following subsections discuss the data and provide the rationale for establishing the baseline emission values in Table 1-2 and the post-modification emissions estimates in Table 1-3. The subsections are organized according to model plant combustion technology. The data used to establish baseline emissions are compiled from emission tests performed at plants that comprised the existing MWC population. The emission tests can be categorized as three distinct types:

1. Compliance tests with sampling performed at the stack, downstream of flue gas cleaning equipment. In most cases these data were generated under optimal operating conditions at or near design steam load. In many cases process data such as temperatures and airflows were not recorded during testing.

2. Compliance tests with sampling performed concurrently at the inlet and outlet of the flue gas cleaning equipment. In most cases, limited process data were recorded, and the combustor operated at or near design steam load.

3. Parametric tests involving multipoint sampling under a variety of combustor and/or flue gas cleaning device operating conditions. Process data are usually well documented in these test reports.

The emissions data used in this analysis are presented both in tabular and graphical form. The data tables present multiple run averages reported for each test facility. Data measured in a parametric test are averaged and presented separately for each parametric operating condition. Combustor design and operating data are also included in the data summary tables. The data graphs present the emission levels for each sampling run, along with an average value for each testing condition.

Test reports that include emissions measured upstream of flue gas cleaning equipment provide the best data to evaluate combustion conditions. As a result, emission tests in categories 2 and 3 are the primary focus of this analysis. In some cases, data measured in the stack also provide information related to combustion conditions. When these data offer some insight into the combustion conditions experienced during testing, they are also included in the discussion of baseline emissions.

3.1 Mass Burn Waterwall MWCs

Twenty-four facilities comprise the population of existing mass burn waterwall MWCs. Facility design and operating data are summarized in Table 3-1. Individual combustor unit sizes in this group range from 50 to 1050 tpd, with one to four units per plant site. The oldest existing mass burn waterwall MWC is located at the Naval Shipyard in Norfolk, VA. This plant commenced operation in 1967. Four of the existing plants began operating in the 1970's; the remaining 19 facilities commenced operation in this decade. The Harrisburg, PA, and Glen Cove, NY, plants burn mixtures of sewage sludge and municipal solid waste; all other plants generally burn 100 percent MSW.

Eight of the 24 facilities use Martin grates. Six plants are equipped with Von Roll grates and five with Detroit Stoker grates. Most European manufacturers (Martin, Von Roll, and others) have American licensees that own the marketing rights of a technology in the U.S. A more detailed discussion on individual combustor designs is provided in the MWC Report to Congress.[5] Other stoker designs used in the existing population include Riley/Takuma and Morse Boulger.

Seventeen of the 24 existing facilities are equipped with ESP emission control systems and seven plants use acid gas controls. Spray dryers are in place at Jackson, MI; Marion County, OR; Commerce, CA; and Millbury, MA. The Alexandria, VA MWC is equipped with an in-furnace lime injection system; Claremont, NH uses in-duct lime injection. With the exception of Millbury and Alexandria which use ESPs, all of the plants with acid gas controls use fabric filters for PM control. All seven of these facilities have begun operating in the last 2 years.

Three model plants were developed to represent groups of conventional mass burn waterwall MWCs. The model plants are designated large, mid-size, and small based on individual unit capacities. Large plants include facilities with unit capacities greater than 600 tpd (545 Mg/day); mid-size plants have unit capacities between 200 and 600 tpd (182 and 545 Mg/day); small plants have unit capacities less than 200 tpd (182 Mg/day).

TABLE 3-1. EXISTING MASS BURN WATERWALL COMBUSTORS

PLANT LOCATION	MANUFACTURER STOKER/BOILER	# OF UNITS	INDIVIDUAL UNIT SIZE tpd	Mg/day	YEAR OF START-UP	APCD	ESP INLET TEMPERATURE °F	°C
Saugus, MA	Von Roll/ Dominion Bridge	2	750	682	1975	ESP	450	232
Pinellas County, FL	Martin/Riley	3	1050	954	1983	ESP	500	260
Westchester County, NY	Von Roll/B&W	3	750	682	1984	ESP	455	235
Baltimore, MD	Von Roll/B&W	3	750	682	1985	ESP	400	204
North Andover, MA	Martin/Riley	2	750	682	1985	ESP	500	260
Millbury, MA	Von Roll/B&W	2	750	682	1988	SD/ESP	-	-
Bridgeport, CT	Von Roll/B&W	3	750	682	1988	SD/FF	-	-
Chicago, IL (NW)	Martin/IBW	4	400	364	1970	ESP	428	220
Harrisburg, PA	Martin/IBW	2	360	327	1973	ESP	500	260
Nashville, TN	Detroit Stoker/	2	360	327	1974	ESP	500	260
	B&W	1	400	364	1986	ESP	450	232
Tulsa, OK	Martin/Zurn	2	375	341	1986	ESP	375-505	191-263
Marion County, OR	Martin/Zurn	2	275	250	1986	SD/FF	-	-
Hillsborough County, FL	Martin/Riley	3	400	364	1987	ESP	375-505	191-263
Commerce, CA	Detroit Stoker/ Foster Wheeler	1	350	318	1987	SD/FF	-	-
Alexandria, VA	Martin/Keeler Dorr-Oliver	2	325	295	1987	infurnace lime inj/ ESP	375-505	191-263
Norfolk Naval Sta., VA	Detroit Stoker/ Foster Wheeler	2	180	164	1967	ESP	690	366
Hampton, VA	Detroit Stoker/ Keeler	2	100	91	1980	ESP	425	218
Harrisonburg, VA	Morris Boulger/ Zurn	2	50	45	1982	ESP	550	288
Glen Cove, NY	Morris Boulger/ Zurn	2	125	114	1983	ESP	560	293
New Hanover County, NC	Detroit Stoker/ Keeler	2	100	91	1984	ESP	425	218
Jackson County, MI	Riley/Takuma	2	100	91	1987	SD/FF	-	-
Key West, FL	Morse Boulger/ Zurn	2	75	68	1987	ESP	450	232
Olmstead County, MN	Riley/Takuma	2	100	91	1988	ESP	425	218
Clarmont, NH	Von Roll	2	100	91	1987	duct lime inj/FF	-	-

3.1.1 Large Mass Burn Waterwall MWCs

Seven MWCs are included in this subcategory of existing mass burn waterwall population. All seven plants are Wheelabrator facilities. Although the new Wheelabrator designs all use Von Roll grate technology, two of the existing plants (North Andover and Pinellas County) have Martin grates. The available emissions data for each of the facilities are summarized in Table 3-2, along with a summary of combustor design and operating practices. Additional discussion regarding emissions data and system design and operation is provided for each facility below. Combustor operating conditions are presented as reported during the actual testing period, or as reported by facilities in response to information questionnaires.

3.1.1.1 Millbury, Massachusetts

Wheelabrator Environmental Systems is the U.S. licensee of Von Roll technology. One of the newest Wheelabrator plants in operation is the Millbury, MA Resource Recovery Facility, which includes two 750 tpd (682 Mg/day) combustors. Each unit is equipped with a spray dryer and an ESP. The facility began operating in 1987 and underwent compliance testing in early 1988. In addition to performing stack testing for compliance purposes, emissions were measured at the spray dryer inlet location. Five CDD/CDF emission samples were gathered at the spray dryer inlet location at Unit #2, and average emissions were 170 ng/dscm CDD/CDF.[14] Individual runs ranged from 140 to 210 ng/dscm. Average CO emissions were 38 ppmv (4-hour average) during the five test runs. The average gas temperature at the inlet sampling location ranged from 429 to 442°F (221 to 228°C) during the five runs.

An assessment of the combustor design at Millbury indicates that the majority of design elements are in place to provide good combustion. Furnace temperatures are measured at the inlet and outlet of the superheater. The thermocouple at the superheater inlet location is approximately 35 feet (10.7 m) above the last point of overfire air injection, and a typical operating temperature at this location is 1500°F (816°C). Millbury has five individually controllable underfire air plenums along the length of the reciprocating grates. One design feature at Millbury that differs from older Von Roll systems is the overfire air capacity. The overfire air system has the capacity to supply 60 percent of total combustion air. The Millbury units operate with 40-50 percent of total air supplied as overfire air. Many Von

TABLE 3-2. LARGE MASS BURN WATERWALL MWCS - PERFORMANCE ASSESSMENT
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FACILITY	Millbury, MA
NUMBER OF UNITS - Flue gas cleaning equipment (FGC)	2 - SD/ESP
UNIT SIZE, tpd (Mg/day)	750 (682)
UNCONTROLLED EMISSIONS	
CDD/CDF (ng/dscm)	170
CO (ppmv)	38
PM (mg/dscm)	NA
CONTROLLED EMISSIONS	
CDD/CDF (ng/dscm)	59.2
CO (ppmv)	--

COMBUSTION PARAMETERS	GOOD COMBUSTION PRACTICE RECOMMENDATIONS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN		
Temperature at fully mixed height	1800°F (982°C) mean	1500°F (816°C) at superheater inlet
Underfire air	At least 4 plenums along grate length	5 plenums along grate length
Overfire air capacity (not an operating requirement)	40% total air	At least 60% total air
Overfire air injector design	Complete penetration/ coverage	3 rows (2 front, 1 rear)
Auxiliary fuel capacity	As required to achieve temperature limits during start-up	Gas - 40% load
Exit gas temperature	<450°F (232°C) at PM control device inlet	435°F (224°C)
OPERATION		
Excess air	6-12% O_2 (dry)	10.2% O_2
Turndown	80-110% design load	Baseloaded - 100% ±3%; 66% minimum
Overfire air	Penetration and coverage of furnace cross section	40-50% total air
Start-up procedures	Auxiliary fuel to design temperature	Gas - 1500°F (816°C) at superheater inlet
Auxiliary fuel use	High CO, low temp; start-up/shutdown	Start-up/shutdown
VERIFICATION		
O_2 levels	Monitor	Yes
CO	Monitor (<50 ppm at 7% O_2)	Yes
Temperature	Monitor	Superheater inlet/ outlet
Air distribution	Monitor	OFA, UFA pressures
Exit gas temperature	Monitor	Yes

TABLE 3-2. LARGE MASS BURN WATERWALL MWCS - PERFORMANCE ASSESSMENT

FACILITY	Pinellas County, FL	Westchester County, NY
NUMBER OF UNITS - FGC	3 - ESP	3 - ESP
UNIT SIZE, tpd (Mg/day)	1050 (954)	750 (682)
UNCONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	69	440
CO (ppmv)	4	15
PM (mg/dscm)	2250	3450
CONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	132	179
CO (ppmv)	--	--
COMBUSTION PARAMETERS	FACILITY DESIGN AND OPERATING CONDITIONS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN		
Temperature at fully mixed height	1700°F (927°C)	NA
Underfire air	5 plenums along grate length	5 plenums along grate length
Overfire air capacity (not an operating requirement)	At least 25% total air	At least 40% total air
Overfire air injector design	2 rows (1 front, 1 rear)	3 rows (2 front, 1 rear)
Auxiliary fuel capacity	None	Gas - 15% load
Exit gas temperature	450-550°F (232-288°C)	455°F (235°C)
OPERATION		
Excess air	8-10% O2 at full load 9-11% O2 at minimum load	9% O2
Turndown	70-90% design load	Baseloaded - 100% Minimum load - 75%
Overfire air	25% of total air	40% total air
Start-up procedures	No auxiliary fuel	Gas to 700°F (371°C)
Auxiliary fuel use	None	Start-up only
VERIFICATION		
O2 levels	Yes	Yes
CO	No	Yes
Temperature	Furnace roof, super-heater inlet/outlet	Superheater inlet/outlet, economizer outlet
Air distribution	OFA pressure, UFA damper settings	OFA, UFA pressures
Exit gas temperature	Yes	Yes

TABLE 3-2. LARGE MASS BURN WATERWALL MWCS - PERFORMANCE ASSESSMENT

FACILITY	North Andover, MA	Saugus, MA
NUMBER OF UNITS - FGC	2 - ESP	2 - ESP
UNIT SIZE, tpd (Mg/day)	750 (682)	750 (682)
UNCONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	246	--
CO (ppmv)	43	--
PM (mg/dscm)	2230	--
CONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	362	490
CO (ppmv)	--	40
COMBUSTION PARAMETERS	FACILITY DESIGN AND OPERATING CONDITIONS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN		
Temperature at fully mixed height	NA	NA
Underfire air	5 plenums along grate length	6 plenums along grate length
Overfire air capacity (not an operating requirement)	At least 40% total air	At least 40% total air
Overfire air injector design	2 rows	4 rows
Auxiliary fuel capacity	None	None
Exit gas temperature	500°F (260°C)	450°F (232°C)
OPERATION		
Excess air	11% 02	8-10% 02
Turndown	Baseloaded - 100% Minimum load - 52%	Baseloaded - 100% Minimum load - 50%
Overfire air	40% of total air	30-40% total air
Start-up procedures	No auxiliary fuel	No auxiliary fuel
Auxiliary fuel use	None	None
VERIFICATION		
02 levels	Yes	Yes
CO	Yes	No
Temperature	5 points in boiler	Superheater inlet, economizer outlet
Air distribution	OFA, UFA pressures	OFA/OFA flows
Exit gas temperature	Yes	Yes

Roll facilities constructed prior to Millbury operate with 30-40 percent of total airflow as overfire.

The majority of operation/control and verification elements representing good combustion practice are also in place at Millbury. The units typically operate at full capacity generating electricity, so low load operation is infrequent. All the recommended monitoring procedures are in place at Millbury.

3.1.1.2 Pinellas County, Florida

The Pinellas County MWC consists of three 1050 tpd (954 Mg/day) combustors, with Martin stokers and three-field ESPs. The #1 and #2 units started up in 1983, and #3 commenced operation in 1986. Six ESP inlet/outlet CDD/CDF emission tests were conducted at Unit #3 in February and March 1987. Average inlet emissions were 69 ng/dscm and average CDD/CDF emissions in the stack were 132 ng/dscm.[9] Average flue gas temperatures at the ESP inlet location ranged from 523 to 553°F (273 to 289°C). Average PM and CO values measured at the ESP inlet were 0.98 gr/dscf (225 mg/dscm) and 4 ppmv, respectively. The CO emissions were measured concurrently with CDD/CDF testing, which was 3 hours' duration. Boiler #3 operated between 88 and 91 rated capacity during the six test runs, and O_2 concentrations varied from 6.9 to 7.7 percent (wet basis). Average furnace temperatures reported during testing varied from 1824°F (996°C) to 1923°F (1051°C), measured in the upper furnace. Underfire and overfire air plenum pressures were recorded and were fairly consistent during all of the runs. Actual airflow splits are not available.

The design of the Pinellas County plant meets the majority of criteria required for good combustion. However, Pinellas County does not have auxiliary fuel burners. In addition, the normal ESP operating temperature is approximately 500°F (260°C). The ESP temperature is assumed to have contributed to the increased CDD/CDF concentrations measured at the ESP outlet location. Based on the emission test results (low organics and CO levels), it is concluded that the unit achieves good mixing. The three units at Pinellas County are operated on a manual combustion control scheme, with the exception that steam production rates are automatically controlled. The majority of mass burn waterwall MWCs are equipped with fully automatic combustion controls. A manual control scheme may allow greater potential for combustion upsets to occur. With the exception that the units do not monitor CO continuously, Pinellas County has all of the verification measures in place to ensure good combustion practices are maintained.

3.1.1.3 Westchester County, New York

The Westchester County, NY, plant includes three 750 tpd (682 Mg/day) Von Roll combustors, each equipped with a three-field ESP. The plant was tested for CDD/CDF as part of a two-phase program. Phase I, completed in 1985, involved only three sampling runs performed in the stack downstream of the ESP. The average CDD/CDF concentration was 102 ng/dscm.[15] Histograms are presented in the test report showing CO levels and superheater gas temperatures measured during run #2. The CO data vary between 10 and 20 ppmv during the 4-hour testing period. The superheater gas temperature was approximately 1100°F (593°C). There are no other process data available in the report.

Phase II of the testing program at Westchester was a parametric testing effort designed to examine the effects of combustor operating conditions on MWC emission levels. Samples of CDD/CDF were gathered in flue gases at three locations in the system (superheater exit, ESP inlet, and ESP outlet) during the following test conditions:

- end of campaign (prior to scheduled maintenance)
- beginning of campaign (after scheduled maintenance)
- high load (115 percent of design)
- low load (85 percent of design)
- cold start-up (with gas preheat)

The emission results from the parametric test are summarized in Table 3-3.[12] The CDD/CDF results presented for each sampling condition are three-run averages. The CDD/CDF emissions are relatively low at the superheater exit during all test conditions. As the gas temperatures were reduced between the superheater exit location and the ESP inlet, average CDD/CDF concentrations increased. This trend occurred during all conditions except low load, where an 11 percent reduction in average CDD/CDF concentration was measured.

Reductions in CDD/CDF concentration were measured between the ESP inlet and outlet during all operating conditions. The reduction in CDD/CDF

TABLE 3-3. DATA SUMMARY - WESTCHESTER COUNTY PARAMETRIC TEST*

	SUPERHEATER EXIT	ESP INLET	ESP OUTLET
<u>CDD/CDF</u>	ng/dscm	ng/dscm	ng/dscm
End	184	619	179
Beginning	122	478	262
High	301	438	126
Low	255	228	148
<u>CO</u>	ppmv	ppmv	ppmv
End	16 (2 runs)	7	7
Beginning	31	24 (1 run)	24 (1 run)
High	35	35	35
Low	38	22	22
<u>PM</u>	gr/dscf (mg/dscm)	gr/dscf (mg/dscm)	gr/dscf (mg/dscm)
End	1.32 (3040)	1.86 (4280)	.0228 (53.4)
Beginning	1.66 (3820)	1.35 (3110)	.0137 (31.5)
High	1.61 (3700	1.89 (4350)	.0133 (30.6)
Low	1.28 (2940)	0.89 (2050)	.0142 (32.7)
<u>Gas Temperature</u>	°F (°C)	°F (°C)	°F (°C)
End	1180 (638)	471 (244)	445 (229)
Beginning	1119 (604)	445 (229)	424 (218)
High	1139 (615)	454 (234)	433 (223)
Low	1034 (557)	437 (225)	415 (213)

*Three run average unless otherwise noted concentration ranged from 35 percent during the low load condition to 71 percent during the end of campaign and high load conditions. The CDD/CDF reductions do not appear to be solely the result of ESP operating temperature. The two highest CDD/CDF reductions occurred during operating conditions where ESP temperatures were highest (end of campaign and high load). The CDD/CDF formation reactions occur while CO levels remain relatively low. These data support the conclusions concerning the CDD/CDF and CO relationship. High CO is a general indicator of high CDD/CDF; however, low CO can be present with variable CDD/CDF emissions.

The Westchester facility meets the majority of recommendations for good combustion practice. The plant generates electricity and operates at full load whenever possible.

3.1.1.4 North Andover, Massachusetts

The available emissions data from North Andover consist of three CDD/CDF sampling runs at the ESP inlet and five runs in the stack. The plant comprises two Martin units, each rated at 750 tpd (682 Mg/day). The ESP inlet sampling was performed by EPA in 1986 in conjunction with State compliance testing. The average inlet CDD/CDF concentrations were 246 ng/dscm.[8] Three simultaneous stack test runs averaged 344 ng/dscm. The ESP inlet temperature during testing varied from 580 to 591°F (304 to 311°C) with an average value of 585°F. Two additional stack test runs are available, but the corresponding inlet runs were invalidated due to sampling or process problems experienced in the field. The average stack emission rate was 382 ng/dscm using all five runs.

Average CO emissions were also relatively constant (average value 43 ppmv). Review of the CO histograms indicated no significant spikes during the three ESP inlet runs. Particulate emissions were not measured at the ESP inlet during CDD/CDF testing runs. Sampling performed separately from the CDD/CDF emission runs indicated an average ESP inlet PM grain loading of 0.97 gr/dscf (2230 mg/dscm).

Some process data were gathered during the emissions test, including steam load, airflows, and temperatures. The units operated near 95 percent design steam load at 90-100 percent excess air during the CDD/CDF tests. With the exception of the ESP inlet gas temperature and the lack of auxiliary fuel supplies, the North Andover facility meets recommendations for good combustion practice.

3.1.1.5 Saugus, Massachusetts

Stack compliance testing was performed in 1986 at the Saugus, MA facility, the oldest existing Wheelabrator plant. The plant began operating in 1975. Seven sampling runs were performed in June 1986 and three runs were performed in August 1986. Both tests were completed at normal operating conditions. Emissions ranged from 486 to 897 ng/dscm in June and 425 to 928 ng/dscm in August.[16] The highest and lowest three-run averages from the June test were 570 ng/dscm and 773 ng/dscm, respectively. Average emissions in the August test were 490 ng/dscm. The combustor was operated between 81 and 84 percent of full steam load with excess air levels ranging from 67 to 96 percent. Overfire air comprised approximately 40-45 percent of total airflow. The average ESP operating temperature during testing was approximately 550°F (288°C). As a result, it is judged that some of the CDD/CDF in the stack resulted from formation that occurred in the ESP. Average CO emissions during the test were 41 ppmv (4-hour average).

Information obtained from a Section 114 questionnaire response indicates that the ESP operating temperatures have been lowered by approximately 100°F (38°C) at Saugus. This modification is expected to reduce CDD/CDF stack emissions by minimizing the potential for catalytic formation reactions to occur in the ESP. With the exception of lacking an auxiliary fuel source and CO monitors, the Saugus facility meets the recommended good combustion practices.

3.1.1.6 Baseline Emission Estimates

The available unabated CDD/CDF emissions data from existing MWCs represented by the large mass burn waterwall model plant are plotted in Figure 3-1. The data include measured emissions from four existing facilities (Millbury, North Andover, Pinellas County, and Westchester County). Individual sampling runs and multiple averages are included for each facility. Data generated during different parametric operating conditions are presented separately for the Westchester MWC.

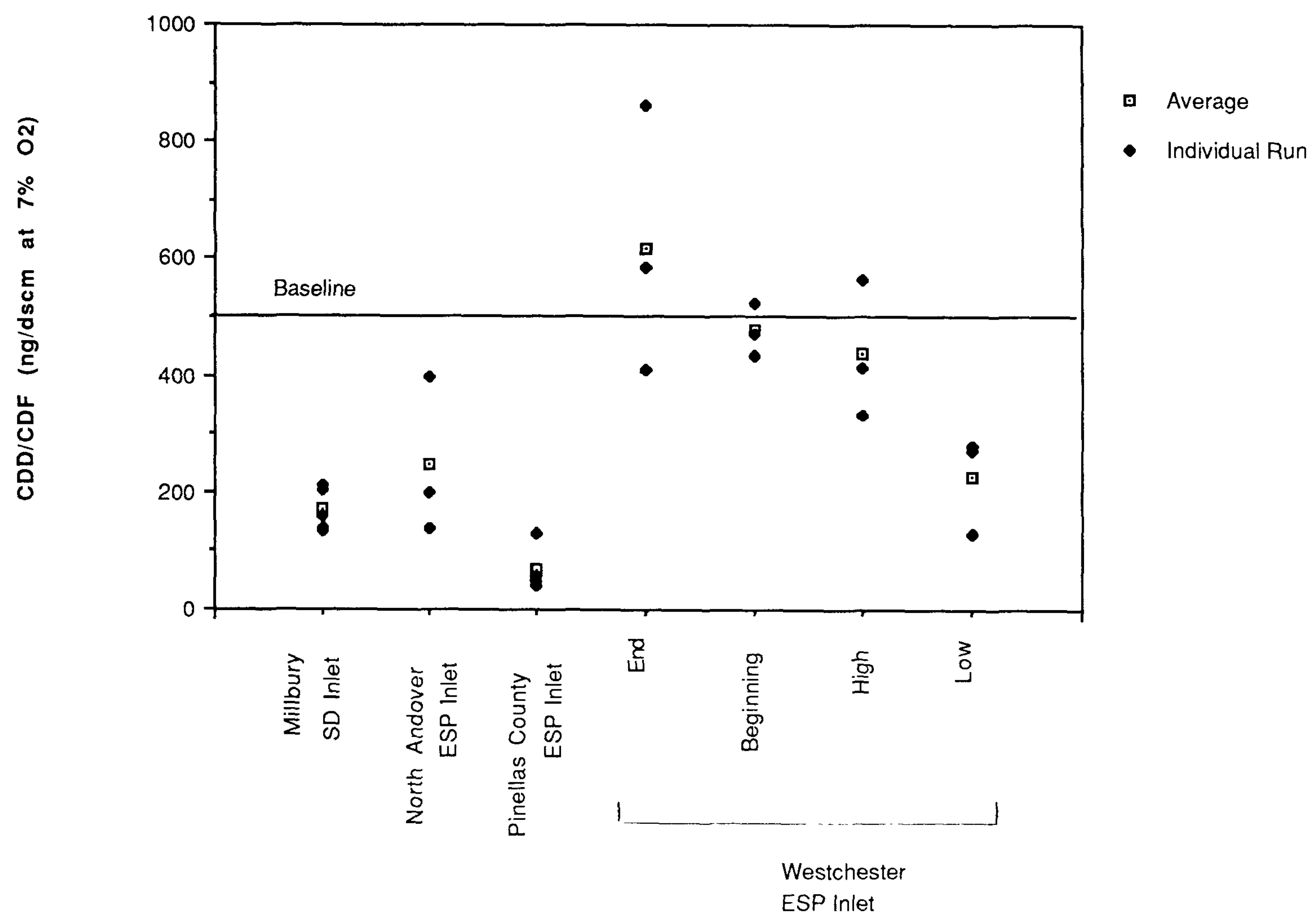

Figure 3-1. Large Mass Burn Waterwall Baseline Determination

Three of the plants achieved CDD/CDF emissions less than 250 ng/dscm. All three of these tests were compliance tests. The Westchester facility exhibited more variable ESP inlet emissions, with averages ranging from 228 to 618 ng/dscm. All of the parametric operating conditions experienced during the Westchester sampling program may be considered "normal operation" with the possible exception of the high load condition, where steam flows were 115 percent of design. Therefore, the range of emissions measured during the parametric test at Westchester reflects the variation in CDD/CDF that can be expected during normal operating conditions in an MWC. The three compliance tests do not show these variations. Baseline (unabated) CDD/CDF emissions of 500 ng/dscm were established for the large mass burn waterwall model plant.

Figure 3-2 presents a graphical summary of available CDD/CDF data measured downstream of ESP controls. The average data from the Saugus facility (6/86 test) exceeds the baseline (500 ng/dscm). Based on the operating temperature of the ESP during the test, it is judged that the CDD/CDF emissions may have increased from ESP inlet levels as a result of formation in the ESP. Although the amount of CDD/CDF formation cannot be quantified based on the available data, it is assumed that the inlet CDD/CDF emissions at Saugus are below the established baseline.

There are seven existing facilities represented by the large mass burn waterwall model plant. CDD/CDF emissions data are available for all plants except Baltimore, MD and Bridgeport, CT. The Baltimore plant is nearly identical in design to the Westchester facility, and the Bridgeport and Millbury combustors also use the same design. Therefore, it is judged that the emissions performance of the two plants is similar, and all plants in this subcategory are expected to be able to achieve the baseline CDD/CDF emissions.

The available CO data from conventional mass burn waterwall MWCs of all sizes indicates that the majority of facilities can achieve 50 ppmv CO on a 4-hour average. Thus, the baseline emission level was established at 50 ppmv. Inlet particulate emissions will vary according to boiler design, air distribution, and waste characteristics. For example, facilities that operate with high underfire/overfire air ratios or relatively high excess air levels may entrain greater quantities of PM and have higher uncontrolled emissions. Boilers with multiple passes that change the direction of flue gas flow in the convective section may remove greater quantities of entrained PM prior to entering flue gas cleaning equipment. Lastly, the physical properties of

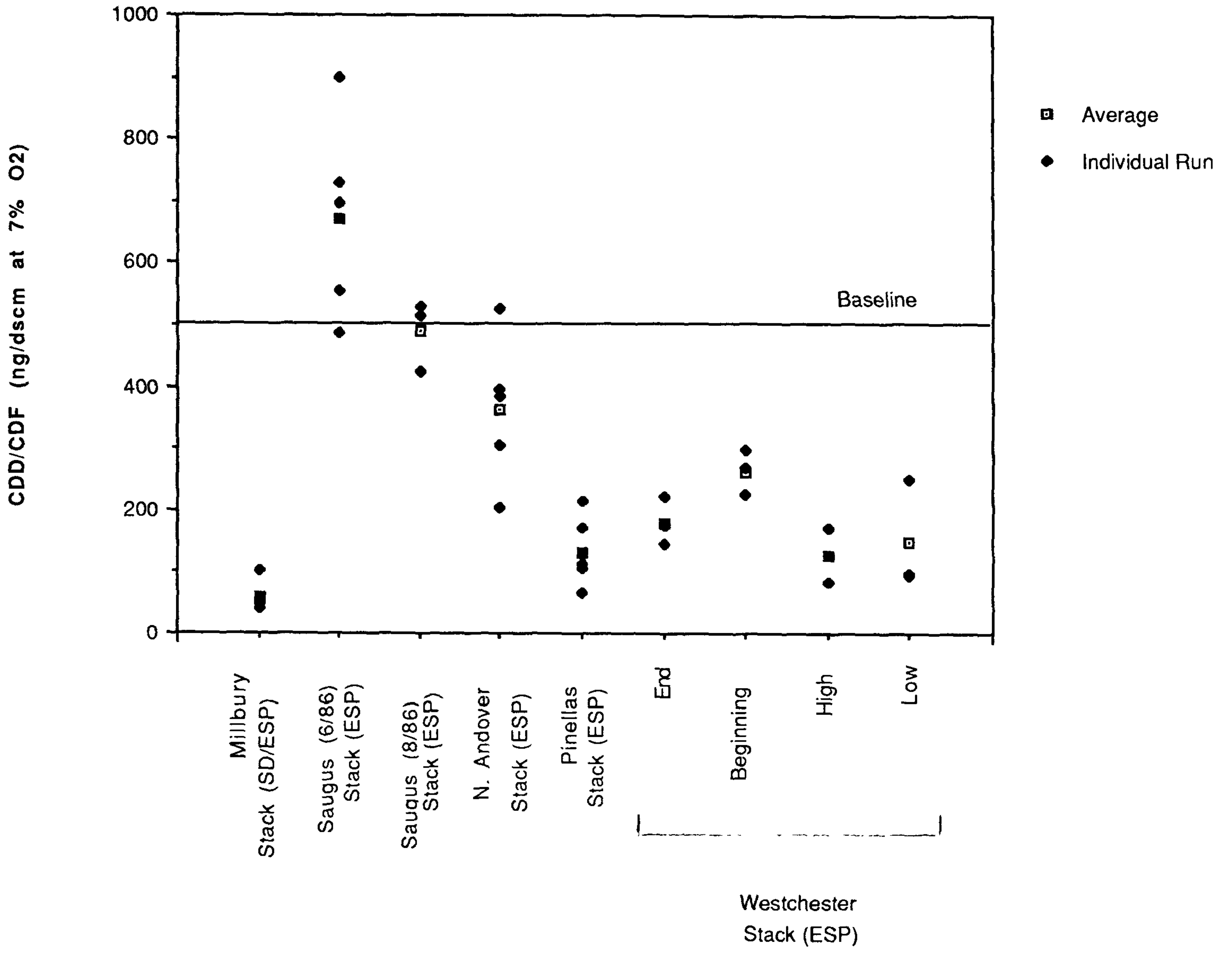

Figure 3-2. Large Mass Burn Waterwall Baseline Determination

waste being fed to a unit may impact the amount of PM that becomes entrained. The available data for the units discussed above ranges from 0.97 gr/dscf (2230 mg/dscm) at North Andover to 1.50 gr/dscf (3520 mg/dscm) at Westchester. Because all of the data are less than 2 gr/dscf (4600 mg/dscm), this value was selected as the baseline.

3.1.1.7 Emission Reductions Resulting from Combustion Modifications

The performance of the model plant representing large mass burn waterwall MWCs was judged to achieve good combustion. The only recommended modification was the addition of continuous CO monitors to verify good mixing and stable combustion conditions.

3.1.2 Mid-Size Mass Burn Waterwall MWCs

Eight existing MWCs are included in this subcategory of the mass burn waterwall population. Six of the facilities use Martin grates and two use Detroit Stoker grates. The available emissions data for each of the facilities are summarized in Table 3-4, along with a summary of combustor design and operating practices. Additional discussion regarding emissions data and system design and operation is provided for each facility below.

3.1.2.1 Commerce, California

The Commerce, CA, MWC consists of one 350 tpd (318 Mg/day) unit with Detroit Stoker grates and a Foster Wheeler boiler. The unit is equipped with a spray dryer/fabric filter. Commerce was also the first MWC in the U.S. to use thermal de-NO_x controls. The facility underwent an emissions test in 1987 for compliance purposes. The CDD/CDF emissions data were measured according to the draft California Air Resources Board (CARB) Modified Method 5 (semi-VOST) protocol. Two test runs were conducted at the stack while burning the largely commercial waste normally received at the facility. A third test run was conducted with simultaneous measurement at the boiler exit and stack while burning a residential refuse brought in from Long Beach, California specifically for the test. Steam load was reduced from full load to 80 percent of capacity during the inlet/outlet sampling. During the one test run that was conducted at the spray dryer inlet, 27 ng/dscm CDD/CDF was measured. Inlet PM and CO emissions were 1.56 gr/dscf (3590 mg/dscm) and 16 ppmv (1-hour average), respectively.[17]

TABLE 3-4. MIDSIZE MASS BURN WATERWALL MWCS - PERFORMANCE ASSESSMENT
PAGE 1 OF 3

FACILITY	Commerce, CA
NUMBER OF UNITS - FGC	1 - SD/FF
UNIT SIZE, tpd (Mg/day)	350 (318)
UNCONTROLLED EMISSIONS	
CDD/CDF (ng/dscm)	27
CO (ppmv)	--
PM (mg/dscm)	4620
CONTROLLED EMISSIONS	
CDD/CDF (ng/dscm)	1.70
CO (ppmv)	16

COMBUSTION PARAMETERS	GOOD COMBUSTION PRACTICE RECOMMENDATIONS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN		
Temperature at fully mixed height	1800°F (982°C) mean	1750°F (926°C) at superheater inlet
Underfire air	At least 4 plenums along grate length	6 plenums (2 per grate length)
Overfire air capacity (not an operating requirement)	40% total air	40% total air
Overfire air injector design	Complete penetration/ coverage	5 rows (2 front, 2 rear, 1 side)
Auxiliary fuel capacity	As required to achieve temperature limits during start-up	Gas - 100% load
Exit gas temperature	<450°F (232°C) at PM control device inlet	480°F (249°C)
OPERATION		
Excess air	6-12% O2 (dry)	10% O2 ±2%
Turndown	80-110% design load	70-101% design load
Overfire air	Penetration and coverage of furnace cross section	20-40% total air
Start-up procedures	Auxiliary fuel to design temperature	On gas
Auxiliary fuel use	High CO, low temp; start-up/shutdown	Start-up/shutdown
VERIFICATION		
O2 levels	Monitor	Yes
CO	Monitor (<50 ppm at 7% O2)	Yes
Temperature	Monitor	Yes
Air distribution	Monitor	OFA, UFA pressures
Exit gas temperature	Monitor	Yes

TABLE 3-4. MIDSIZE MASS BURN WATERWALL MWCS - PERFORMANCE ASSESSMENT
PAGE 2 OF 3

FACILITY	Marion County, OR	Alexandria, VA
NUMBER OF UNITS - FGC	2 - SD/FF	3 - FI/ESP
UNIT SIZE, tpd (Mg/day)	275 (250)	375 (341)
<u>UNCONTROLLED EMISSIONS</u>		
CDD/CDF (ng/dscm)	43	--
CO (ppmv)	18	--
PM (mg/dscm)	205	--
<u>CONTROLLED EMISSIONS</u>		
CDD/CDF (ng/dscm)	1.39	53
CO (ppmv)	--	18

COMBUSTION PARAMETERS	FACILITY DESIGN AND OPERATING CONDITIONS	FACILITY DESIGN AND OPERATING CONDITIONS
<u>DESIGN</u>		
Temperature at fully mixed height	1400-1600°F (760-872°C) at superheater inlet	1400-1600°F (760-872°C) at superheater inlet
Underfire air	5 plenums per grate run	5 plenums along grate length
Overfire air capacity (not an operating requirement)	At least 40% total air	At least 40% total air
Overfire air injector design	3 rows	2 rows
Auxiliary fuel capacity	Gas - 30% load	Oil - 25% thermal load
Exit gas temperature	392°F (200°C)	375-505°F (191-263°C)
<u>OPERATION</u>		
Excess air	7-12% O_2	7-12% O_2
Turndown	75-105% design load	80-100% load
Overfire air	20-40% total air	20-40% total air
Start-up procedures	Gas to 1800°F (982°C)	On oil to 1400°F (760°C)
Auxiliary fuel use	Start-up/shutdown	Start-up/shutdown
<u>VERIFICATION</u>		
O_2 levels	Yes	Yes
CO	No	Yes
Temperature	Middle and top of furnace	Furnace exit (superheater inlet)
Air distribution	OFA, UFA pressures	OFA, UFA pressures
Exit gas temperature	Yes	Yes

TABLE 3-4. MIDSIZE MASS BURN WATERWALL MWCS - PERFORMANCE ASSESSMENT
PAGE 3 OF 3

FACILITY	Tulsa, OK	Chicago, IL
NUMBER OF UNITS - FGC	3 - ESP	4 - ESP
UNIT SIZE, tpd (Mg/day)	375 (341)	400 (364)
UNCONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	--	--
CO (ppmv)	--	--
PM (mg/dscm)	--	--
CONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	36	254
CO (ppmv)	22	1-223
COMBUSTION PARAMETERS	FACILITY DESIGN AND OPERATING CONDITIONS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN		
Temperature at fully mixed height	1400-1600°F (760-872°C) at superheater inlet	1470°F (799°C) at convection section inlet
Underfire air	5 plenums along grate run	6 plenums along grate run
Overfire air capacity (not an operating requirement)	At least 40% total air	At least 26% total air
Overfire air injector design	NA	2 rows
Auxiliary fuel capacity	None	Gas - 100% load
Exit gas temperature	375-515°F (191-263°C)	450°F (232°C)
OPERATION		
Excess air	7-12% 02	8-10% 02
Turndown	72-100% load	NA
Overfire air	20-40% total air	26% total air
Start-up procedures	No auxiliary fuel	On gas
Auxiliary fuel use	None	Start-up
VERIFICATION		
02 levels	Yes	Yes
CO	Yes	No
Temperature	NA	3 locations
Air distribution	OFA, UFA pressures	OFA, UFA pressures
Exit gas temperature	Yes	Yes

The amount of process data included in the emissions test report is fairly limited. Steam load varied from 80 to 103 percent of capacity during the test. The thermal de-NO_x system was operational throughout the testing period except for one test run when the NO_x levels were measured without ammonia injection. This control system demonstrated NO_x reduction in excess of 40 percent. The report contains no information on combustion air operating levels.

The Commerce facility has all of the design components of good combustion in place. It is judged that the 1700°F (927°C) superheater inlet temperatures correspond to a temperature at the fully mixed height which meets the good combustion recommendations. The operation of the facility is maintained by a fully automatic control system. The unit generates electricity, operating at full load whenever possible. All of the verification measures are in place to monitor continuous performance and ensure good combustion.

3.1.2.2 Marion County, Oregon

The Marion County, OR MWC consists of two 275 tpd (250 Mg/day) Martin combustors equipped with spray dryers and fabric filters. The units commenced operation in 1986. During stack compliance testing in September 1986, EPA performed three sampling runs at the boiler outlet (spray dryer inlet) location. Two of the three sampling runs were invalidated, but the results of the one successful run indicated an inlet CDD/CDF emission rate of 43 ng/dscm. In addition, inlet particulate emissions were 0.89 gr/dscf (2050 mg/dscm), and CO emissions were 18 ppmv (4-hour average).[18]

Process data were recorded during the compliance test at Marion County. The steam load was 97 percent of design load during CDD/CDF testing. Gas temperatures measured in the middle of the first furnace pass averaged 1741°F (949°C), and the average economizer outlet temperature was 392°F (200°C). Average exhaust gas oxygen concentrations were 9.5 percent, and the estimated overfire/underfire air ratio was 25/75. The Marion County units are equipped with auxiliary fuel burners that can provide 30 percent of thermal load. The units do not have continuous CO monitors.

EPA gathered an additional 14 unabated CDD/CDF samples at Marion County in February 1987. During all of the sampling runs, the boiler was operated at normal, full load conditions. Analysis was completed on seven of the runs. Four of the seven samples had acceptable spike recoveries and were full traverse samples. Three of the seven runs were either single point samples or were invalidated due to poor recoveries. The CDD/CDF values from the valid test runs ranged from 56 to 116 ng/dscm, with an average value of 99 ng/dscm.[19]

3.1.2.3 Alexandria, Virginia

The Alexandria, VA facility, which began operating in 1987, consists of three 375 tpd (341 Mg/day) units. The system design includes in-furnace lime injection for acid gas control, and ESPs for PM control. Results of compliance testing performed at Unit #1 in December 1987 indicated a three-run average of 53 ng/dscm CDD/CDF and 18 ppmv of CO (3-hour average) in the stack.[20] Limited process data are included in the compliance test report. The boiler reportedly operated between 98 and 99 percent design steam load during the three runs, and average O_2 concentrations were 9.5 percent. The furnace temperature was measured at an unspecified furnace exit location with an unshielded thermocouple. The average temperature during the three runs was 1651°F (899°C), 1664°F (907°C), and 1642°F (894°C). The test report authors state that the measurement method "should be regarded as being relatively accurate; i.e., lower than the actual temperature by approximately 150-200°F, but precise." The average stack temperature was reported to be 342°F (172°C) while sampling, so it is judged that the ESP temperature was below 450°F (232°C). Although the existing data base does not provide a basis for estimating the effect of dry lime furnace injection on CDD/CDF, the emission levels are typical of those measured at other Martin systems, that do not use acid gas controls.

The facility is judged to satisfy the majority of criteria included in the good combustion practice recommendations. The gas temperatures at the superheater inlet are reported to vary from 1400°F (760°C) to 1600°F (871°C). The plant has an auxiliary fuel source (oil), and the firing capacity is 25 percent of boiler load.

3.1.2.4 Tulsa, Oklahoma

Emissions data from two other facilities using Martin designs were also used to establish baseline emission factors for the model plant. The first of these is the Tulsa, OK facility, which is comprised of three 375 tpd (341 Mg/day) combustor units. The facility began operating in 1986. Each of the units is equipped with an ESP. The ESP inlet gas temperature typically varies from 375 to 515°F (191 to 268°C). Available emissions data gathered for compliance purposes indicates average CDD/CDF emissions of 36 ng/dscm at the stack location.[21] The flue gas temperature during testing was not included in the report. Emissions of CO averaged 22 ppmv at Unit #1 and 27 ppmv at Unit #2. The CO data were gathered separately from the CDD/CDF data, and are presented as 1-hour averages. There are no process data available in the test report to use in evaluating the combustor operating conditions. With the exception that Tulsa does not have auxiliary fuel, all of the requirements of good combustion are assumed to be achieved at this facility.

3.1.2.5 Chicago Northwest, Illinois

The Chicago Northwest MWC is comprised of four units with individual capacities of 400 tpd (364 Mg/day). Each of the units is equipped with Martin stokers and ESP controls. Emissions of CDD/CDF and other organics (total organic chloride, PAH, PCB) were measured in the stack of Unit #2 between April 30 and May 23, 1980. The plant was operated at normal steady state conditions to the greatest extent possible during the tests. The average CDD/CDF emissions in the stack were reported to be 254 ng/dscm.[22] Daily average CO emissions from Unit #2 varied from 1 ppmv to 223 ppmv during the 11 days when organics sampling was performed. The average flue gas temperature in the ESP was 500°F (260°C).

3.1.2.6 Baseline Emission Estimates

The available CDD/CDF emissions data from existing MWCs represented by the mid-size mass burn waterwall model plant are plotted in Figure 3-3. The data include APCD inlet emissions from two plants (Commerce and Marion County) and stack emissions from three facilities (Alexandria, Tulsa, and Chicago NW). With the exception of the Chicago NW data set, all the measured emissions are less than 200 ng/dscm. Although inlet CDD/CDF data are not available from

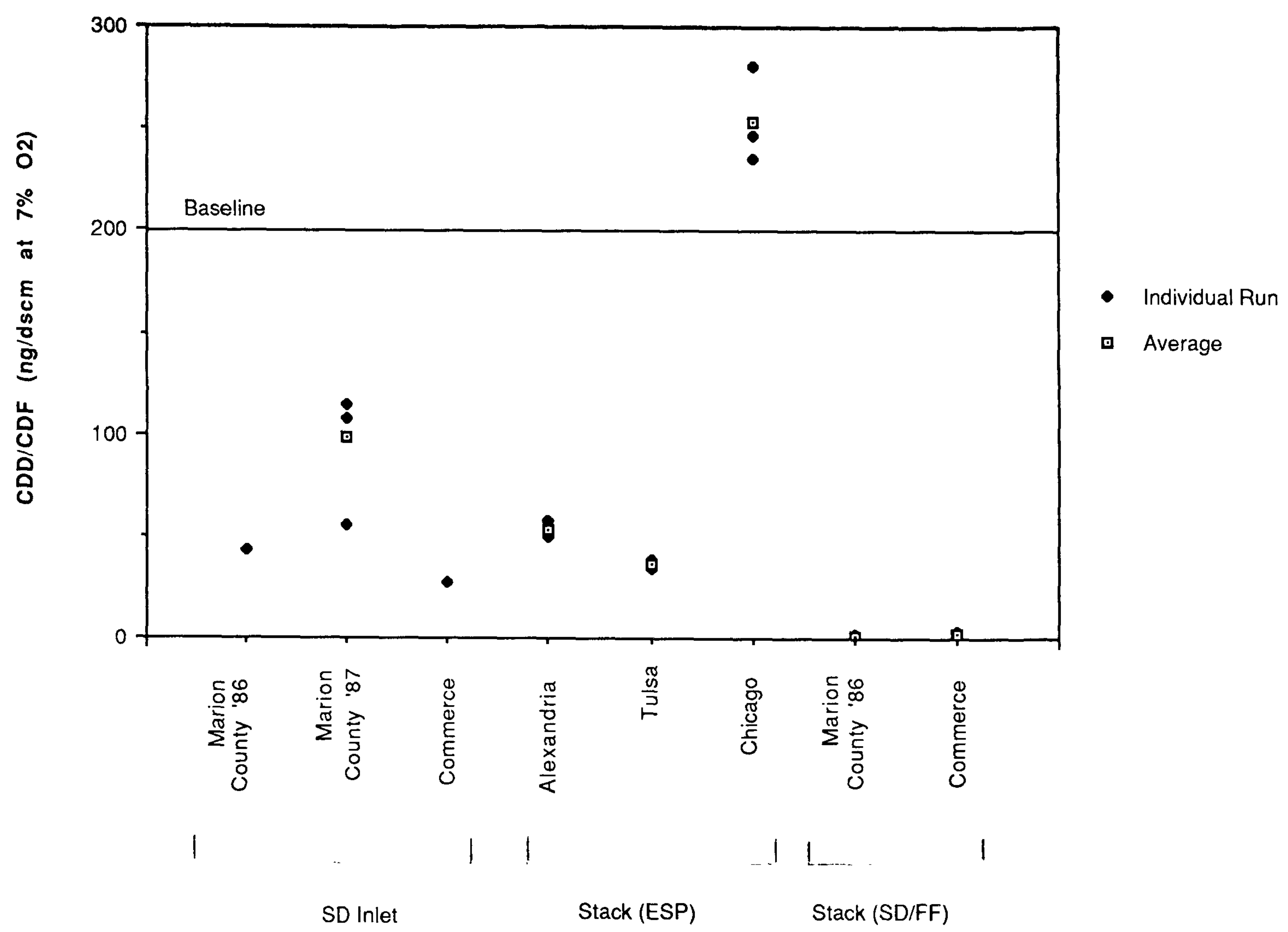

Figure 3-3. Mid-Sized Mass Burn Waterwall Baseline Determination

Chicago NW, it is assumed that the emissions are below 200 ng/dscm, and that the the higher stack concentrations resulted from formation in the ESP. Therefore, all of the plants are assumed to achieve emissions less than 200 ng/dscm, and this value is selected as a baseline APCD inlet emission level. Baseline inlet CO and PM emissions were established at 50 ppmv and 2 gr/dscf (4600 mg/dscm), respectively, using the available data for facilities represented by the model plant. It is assumed that all facilities in the subcategory can achieve the baseline emission levels.

3.1.2.7 Emission Reductions Resulting from Combustion Modifications

The mid-size mass burn waterwall model plant is assumed to satisfy the design and operating criteria in the good combustion practice recommendations. The only recommended modification for the model was the addition of continuous CO monitors to verify good mixing and stable operation.

3.1.3 Small Mass Burn Waterwall MWCs

The existing population of small mass burn waterwall MWCs comprises nine facilities. The nine plants use four separate grate designs, with no single manufacturer dominating this segment of the market. Only two of the plants (Hampton, VA, and Claremont, NH) have reported CDD/CDF data.

3.1.3.1 Hampton, Virginia

The Hampton facility has been tested for CDD/CDF on five separate occasions. Table 3-5 presents an historical emissions summary for the facility.[23,24] In each case, testing was performed in the stack downstream of the ESP. Process data measured during the 1984 test indicated that during normal operating conditions, excess O_2 levels and furnace temperatures were highly variable.[25] In addition, typical ESP operating temperatures were in the range of 550 to 600°F (288 to 316°C). A summary of design and operating parameters is presented for the facility in Table 3-6 for the period during which these tests were performed.

Following the completion of the 1984 emissions test, the plant operators initiated a retrofit program to modify the design and operation of the units.[26] This was not only due to concerns related to emissions, but also due to the need for corrective action to address operating problems that were

TABLE 3-5. CDD/CDF EMISSIONS HISTORY
HAMPTON, VA MWC

YEAR	CDD/CDF (ng/dscm)	NUMBER OF SAMPLING RUNS	CO (ppmv)
1981	25,017	3	--
1982	663*	3	--
1983	10,423	5	1082
1984	22,325	3	209
1986	155	3	24

*1982 data include tetra-CDD/CDF homologues only

TABLE 3-6. SMALL MASS BURN WATERWALL MWCS - PERFORMANCE ASSESSMENT

FACILITY		Hampton, VA (pre-retrofit)
NUMBER OF UNITS - FGC		2 - ESP
UNIT SIZE, tpd (Mg/day)		100 (91)
UNCONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)		--
CO (ppmv)		--
PM (mg/dscm)		--
CONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)		22,325 (1984)
CO (ppmv)		1082 (1983)
COMBUSTION PARAMETERS	GOOD COMBUSTION PRACTICE RECOMMENDATIONS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN		
Temperature at fully mixed height	1800°F (982°C) mean	1300-1600°F (704-871°C) in upper furnace
Underfire air	At least 4 plenums along grate length	3 plenums along grate length
Overfire air capacity (not an operating requirement)	40% total air	<20% total air
Overfire air injector design	Complete penetration/ coverage	No
Auxiliary fuel capacity	As requried to achieve temperature limits during start-up	None
Exit gas temperature	<450°F (232°C) at PM control device inlet	550°F (288°C)
OPERATION		
Excess air	6-12% O2 (dry)	2-10%
Turndown	80-110% design load	NA
Overfire air	Penetration and coverage of furnace cross section	Not achieved
Start-up procedures	Auxiliary fuel to design temperature	No auxiliary fuel
Auxiliary fuel use	High CO, low temp; start-up/shutdown	None
VERIFICATION		
O2 levels	Monitor	Yes
CO	Monitor (<50 ppm at 7% O2)	No
Temperature	Monitor	Yes
Air distribution	Monitor	NA
Exit gas temperature	Monitor	Yes

TABLE 3-6. SMALL MASS BURN WATERWALL MWCS - PERFORMANCE ASSESSMENT
PAGE 2 OF 2

FACILITY	Hampton, VA (post-retrofit)	Claremont, NH
NUMBER OF UNITS - FGC	2 - ESP	2 - DI/FF
UNIT SIZE, tpd (Mg/day)	100 (91)	100 (91)
UNCONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	--	--
CO (ppmv)	--	--
PM (mg/dscm)	--	--
CONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	155	37
CO (ppmv)	24	50-70

COMBUSTION PARAMETERS	FACILITY DESIGN AND OPERATING CONDITIONS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN		
Temperature at fully mixed height	1600°F (871°C) at first convective section inlet	1800-2000°F (982-1093°C) in upper furnace
Underfire air	3 plenums along grate length	4 plenums along grate length
Overfire air capacity (not an operating requirement)	45% total air	40-50% total air
Overfire air injector design	2 rows each on front and rear walls	2 rows (1 front, 1 rear)
Auxiliary fuel capacity	None	Gas - 50% load
Exit gas temperature	425°F (218°C)	500°F (260°C)
OPERATION		
Excess air	7% O_2	9-12% (wet)
Turndown	50-100% design load	60-100%
Overfire air	Achieved - assumed based on CO and CDD/CDF	40-50% total air
Start-up procedures	No auxiliary fuel	Gas
Auxiliary fuel use	None	Start-up/shutdown
VERIFICATION		
O_2 levels	Yes	Yes
CO	Yes	Yes
Temperature	Yes	Yes
Air distribution	Yes, OFA/UFA	OFA/UFA pressures
Exit gas temperature	NA	Yes

plaguing the boilers. The original cast iron grate bars were replaced with high alloy chrome-nickel grates and the life of the grates was extended from 4-6 months to 2-3 years. High alloy blocks were retrofitted on the lower side walls of the furnace, replacing existing silicon carbide refractory, and resulting in improved heat transfer and reduced clinker formation. Steam coil air preheaters were also added to the units for operation during periods of wet waste firing.

The major improvements that were made to reduce emissions were primarily related to combustion airflows and distributions. First, it was determined that the forced draft fan supplying the overfire air was providing less than half its design capacity. The fan blades were modified and the discharge duct size was increased, making the flow more aerodynamic. These modifications restored the overfire air supply to its original design capacity (45 percent of total air). The plant personnel also realized that mixing was not optimized, so they began to evaluate the size and orientation of the overfire air nozzles. There are four rows of overfire air nozzles (two rows on each of the front and rear walls). The orientation of the lower two rows was changed based on visual observations made in the furnace. The angle of the front row was raised from -45° (from the horizontal) to -22.5°. The angle of the rear wall nozzle row was changed from -20° (from the horizontal) to 0° (horizontal). Now the overfire air jets converge at a point approximately 5 feet (1.5 meters) above the grate rather than directly on the grate.

Modifications were also made to the operation and combustion control system. The grate speeds, which were automatically controlled, were switched to manual, which allowed the speed to be varied from 0 to 80 percent rather than 40 to 80 percent. This provided more flexibility to deal with varying waste characteristics (particularly wet waste), and resulted in improved burnout. A 15 point CO profile was performed at the economizer outlet, and it was determined that CO was highest when active burning occurred on the burning grate. When the bed length was extended to provide active burning on the finishing grate, there were problems with solids burnout. An oxygen trim loop was installed which provides automatic control of the underfire air distribution based on the O_2 content of the flue gases. The control loop balances the distribution between the two grates, providing good waste burnout and maintaining 7-9 percent O_2 in exhaust gases.

Finally, the existing economizer was replaced with new tube banks which drop the flue gas temperature to 425°F (218°C) at the ESP inlet. Previously the ESP operated at approximately 550°F (288°C), where the potential for CDD/CDF formation was relatively high. Installation of the new economizer has reduced total fuel consumption on an hourly basis, but this has been offset by increased system availability, so that overall steam output and waste throughput has actually increased.

The most recent emission test performed at Hampton resulted in stack emissions of 155 ng/dscm CDD/CDF and CO levels of 24 ppmv.[24] The design and operating characteristics of the facility following the combustion retrofit are presented in Table 3-6. The design and operating improvements represent a major step toward attainment of good combustion practices. This is well documented by the resulting emission levels, which are presented in Tables 3-5 and 3-6.

3.1.3.2 Claremont, New Hampshire

The second set of CDD/CDF data available from a small mass burn waterwall MWC was measured in 1987 at Claremont, NH. Claremont comprises two 100 tpd (91 Mg/day) units with Von Roll grates. Acid gas control is achieved by in-duct lime injection downstream of the boiler; PM control is achieved by a baghouse. Dilution air is added to the duct prior to the lime injection point in order to provide flue gas temperature reduction. Both units were tested for CDD/CDF as part of a compliance demonstration test. The average emissions (four-run average) in the stack were 38 ng/dscm for Unit #1 and 37 ng/dscm for Unit #2.[27] It is not possible to estimate combustor emissions of CDD/CDF since the effects of the dry injection/fabric filter controls in reducing emission levels of CDD/CDF are unknown. Temperatures in the stack were 418°F (214°C) and 445°F (229°C). Facility design and operating information is presented in Table 3-6.

3.1.3.3 Baseline Emission Estimates

Very limited measured data are available from small mass burn waterwall MWCs. This group of combustors is not dominated by a single system manufacturer such as Von Roll or Martin in the large and mid-size populations. Based on a review of facility design and operating practices, it was determined that there are small mass burn waterwall combustors that satisfy the good combustion criteria, and others that lack some necessary design and operating features associated with good combustion. As an example, one of the facilities visited in the Retrofit Study was the New Hanover County, NC MWC. During the site visit, the plant was reportedly experiencing problems related to erosion and corrosion of heat transfer surfaces similar to those experienced at the Hampton plant.[1] While there are no measured CDD/CDF data from the New Hanover County units, there was reason to anticipate problems similar to those at Hampton related to emissions performance. In fact, a feasibility study was under way to examine potential combustion retrofit options at the plant. The problems experienced at Hampton may not be unique to that facility in the small mass burn waterwall population. However, there are other plants that meet the recommendations for good combustion, and emissions from these facilities are expected to be relatively low. Therefore, the model plant represents only a portion of the facilities in the existing population. It is not intended to represent those plants in the existing population that have good combustion practices in place.

There were no data from existing U.S. plants to use in estimating a baseline except for those measured at Hampton prior to the combustion retrofit. An engineering judgment was made that CDD/CDF emission levels as high as the pre-retrofit Hampton data were not representative for the group of facilities represented by the model. Therefore, these data were not used to establish baseline emission levels.

A data set gathered at a mass burn waterwall MWC in Quebec City, Quebec was used to establish baseline emissions for the model plant. The Quebec City MWC comprises four 250 tpd (225 Mg/day) combustors using Von Roll grates and Dominion Bridge boilers. Emissions control is achieved by two-field ESPs. The plant was the host site for a combustion evaluation and retrofit program performed by Environment Canada in 1985-86.[28] Prior to the combustion evaluation program, Environment Canada also investigated the performance of a pilot-scale acid gas scrubbing system and a baghouse on the control of multipollutant emissions at the Quebec facility.[29] The pilot-scale test included measurement of APCD inlet CDD/CDF emissions in a slipstream drawn from the ESP inlet duct at the #3 unit. The slipstream arrangement was used to direct a flow of combustion gases into a Flakt pilot scale scrubbing system that included a quench reactor, a dry reactor, and a fabric filter. The average CDD/CDF emissions measured during 12 sampling runs at the pilot system inlet were 1840 ng/dscm, and average CO emissions were 370 ppmv. A graphical presentation of the CDD/CDF emissions is shown in Figure 3-4.

The design and operating features of the small mass burn waterwall model plant were assumed to be similar in many respects to those of the Quebec City units prior to the combustion retrofit program. Therefore, the inlet data measured at the Quebec City facility were used to establish baseline emission levels for the model plant, 2000 ng/dscm CDD/CDF and 400 ppmv CO (4-hour average). An average PM emission rate of 2 gr/dscf (4600 dscm) was selected for the model plant.

3.1.3.4 Emission Reductions Resulting from Combustion Modifications

The required modifications for the small mass burn waterwall model plant included flow modeling studies and a redesign of the overfire air nozzle arrangement, installation of auxiliary fuel burners for start-up and shutdown operation, installation of CO monitors to verify combustion conditions, and the addition of an oxygen trim loop to provide automatic adjustment of underfire air distributions. It was estimated that following these modifications, CDD/CDF emissions would be reduced to 200 ng/dscm, and CO emissions would be reduced to 50 ppmv (4-hour average). These emission reduction estimates were made based on results from combustion retrofit programs carried out at the Hampton and Quebec City MWCs.[26,28] Information related to the Quebec retrofit program is summarized below.

3.1.3.4.1 Quebec City, Quebec - Background. The goal of Environment Canada's retrofit program at the Quebec City MWC was to determine the optimum design and operating conditions to minimize air emissions from the unit and to retrofit the system to meet these conditions. A profile of the unmodified design is shown in Figure 3-5. The original design of each combustor includes a vibrating feeder-hopper and a water-cooled chute that feeds the waste by gravity. There are three grates (drying, burning, and finishing) in each unit. The grates have a 15° slope and contain vertical drops between each section. The furnaces are membrane waterwall construction with a refractory-lined burning chamber and a mechanically rapped convective section with superheater and economizer tube sections. Each unit reduces PM emissions with a two-field ESP that operates at temperatures between 392 and 504°F (200 and 280°C). Bottom ash is discharged from the grates to a wet quench tank and removed with a drag chain.

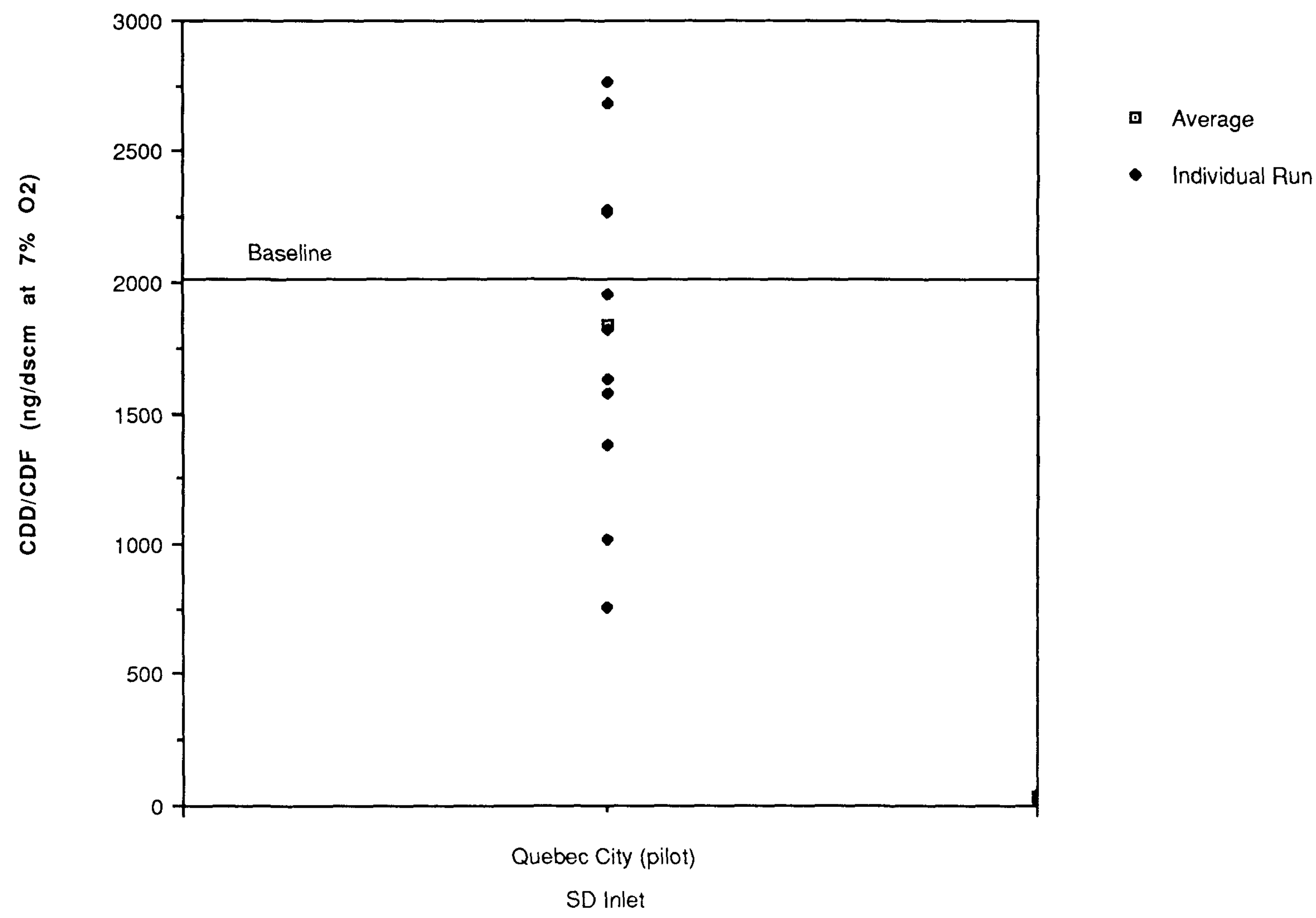

Figure 3-4. Small Mass Burn Waterwall Baseline Determination

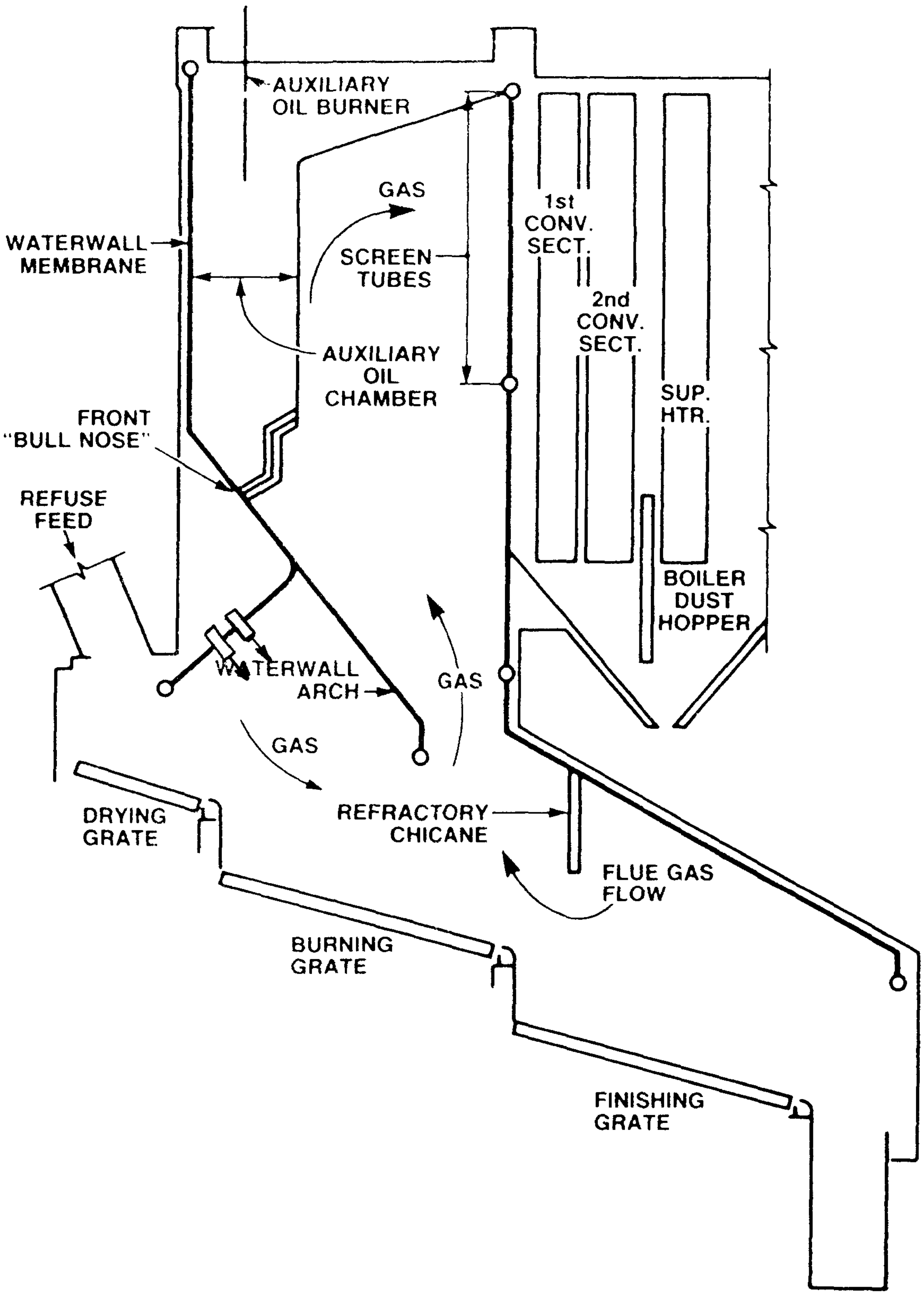

Figure 3-5. Quebec City MWC - Pre-Modification (1978 Design)

In 1979 a waterwall arch (shown in Figure 3-5) was installed above the drying and burning grates. Existing side wall overfire air ports were abandoned in favor of 20 new ports located on the front wall beneath the waterwall arch. An auxiliary oil burner is also located in the upper front furnace; however, it was not used. The underfire air fan supplied approximately 90 percent of the total air flow through five plenums beneath the grates. The control scheme was largely manual, with the exception that total underfire air flows were adjusted automatically to maintain steam flow setpoints.

As mentioned previously, CDD/CDF emissions were measured as part of an investigation of a pilot dry scrubbing/fabric filter control device study. Average control device inlet emissions were 1840 ng/dscm. In 1984 Environment Quebec also conducted CDD/CDF stack testing. Three tests were completed and CDD/CDF stack emission results varied from 800 to 4000 ng/Nm^3.[28] Both of these tests provided a benchmark to compare the effects of the combustion modifications on emission rates.

3.1.3.4.2 <u>Quebec City MWC Modernization Program</u>. The first step in the modernization program was the completion of flow modeling studies to examine the existing furnace flow patterns. The objectives of the modeling studies were to select a configuration where furnace geometry and airflows could provide the best mixing of combustion products and adequate retention times in the furnace for good combustion to occur. The following modifications were made to the combustor as a result of the flow modeling study. A profile of the modified configuration is shown in Figure 3-6.

A lower bull nose was added on the rear furnace wall to maximize the radiation reflection onto the burning and finishing grates, thus providing improved ash burnout. The bull nose was also designed to pinch the flow of combustion gases from the finishing grate to mix the combustion products and complete the burning process. The upper bull nose reduced gas vortices in the upper portion of the furnace, improving gas distribution and reducing stratification at the inlet to the convective section. New overfire air nozzles were installed in the pinched wall section to improve mixing. Various front-to-rear ratios were examined and a 1:1 ratio was chosen because it resulted in the optimal vertical mixing and least amount of stratification at

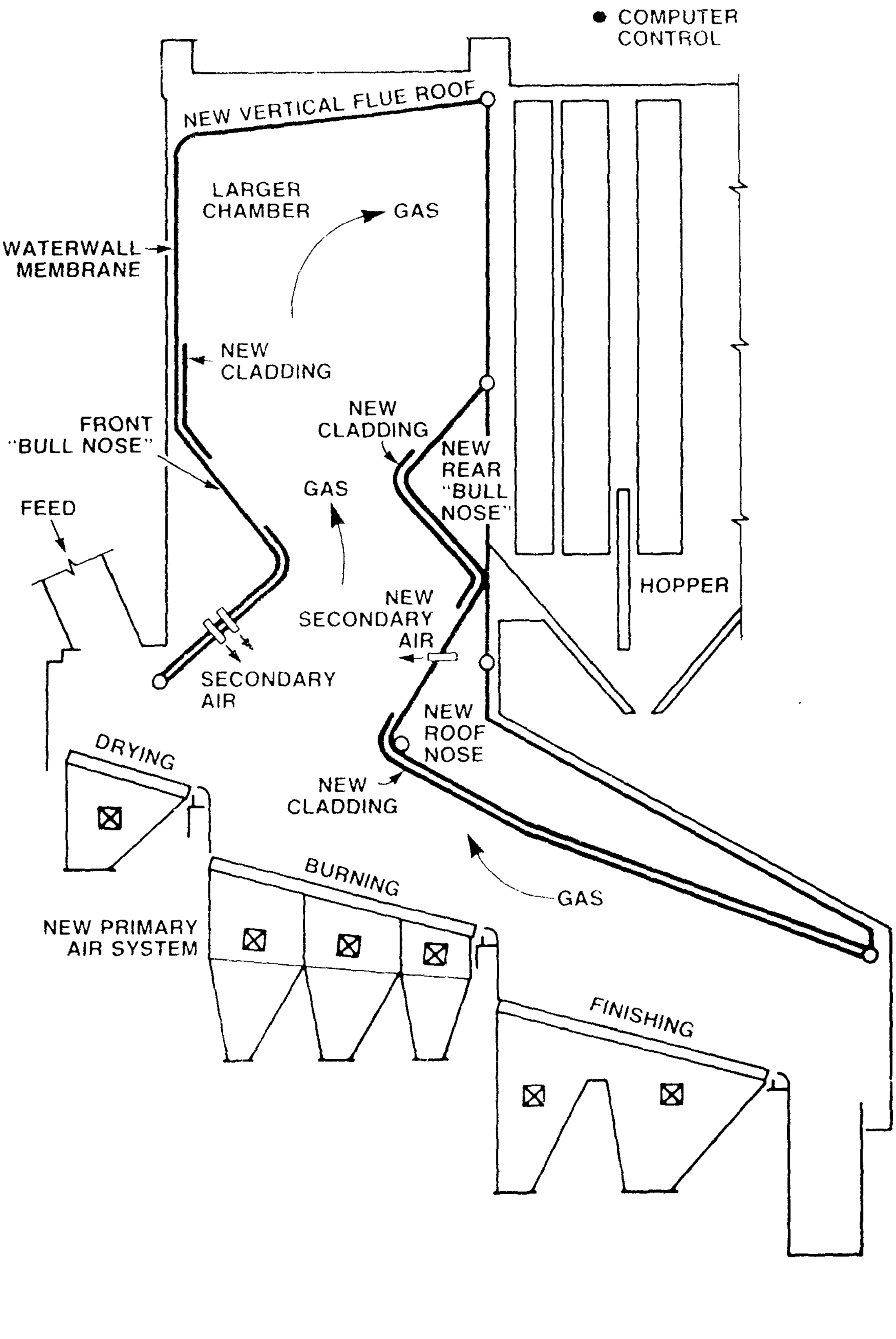

Figure 3-6. Quebec City MWC - Post-Modification (1986 Design)

the inlet to the convective section. The reconfiguration also prevented high velocities in the upper furnace, which helped to reduce PM carryover.

The underfire air supply was redesigned to include nine separate plenums. The arrangement provided a single plenum under the drying grate, six individual plenums beneath the burning grate, and two plenums beneath the burnout grate. Each of the underfire air supplies is individually controlled to maintain a preset distribution. Total underfire airflows are controlled to maintain steam production rates. The underfire air system supplies 65 percent of total combustion air under normal operating conditions and the overfire air system supplies the remaining 35 percent.

A state-of-the-art automatic combustion controller was installed. The system automatically controls grate speed in response to boiler steam flow with an excess air feedback loop to the grate speed controller. Underfire air flows and distributions are maintained automatically and there are provisions in the control system to vary overfire air flow rates in response to temperature readings in the upper furnace.

Following completion of the modernization program, a parametric testing program was conducted to evaluate the effect of the retrofit on emission levels. The first phase, characterization testing, investigated the effects of feed rate, excess air rates, combustion temperatures, and overfire/underfire air ratios on emissions of CO and other continuously measured gases. From the results of characterization testing, a series of performance test conditions were selected for manual sampling of CDD/CDF, and other organic and inorganic pollutants. All sampling was conducted at the ESP exit location. Table 3-7 summarizes the results of the CDD/CDF emissions measured during each performance condition.[28]

The measured emissions data indicate that the combustion modifications resulted in substantial reduction of CDD/CDF and CO emissions. Performance test group #2 (runs 5, 6, 12) can be considered normal operating conditions for the unit. Average CDD/CDF emissions were reported to be 64 ng/dscm during the three runs, and average CO emissions were 28 ppmv. Test groups #3 (runs 14 and 15) and #4 (runs 2 and 3) were representative of poor operating conditions at design steam load. Test groups #1, #5, and #6 investigated the effects of steam load on emissions performance. Excess air levels were also varied during these conditions.

TABLE 3-7. QUEBEC CITY PARAMETRIC TEST - EMISSIONS SUMMARY

TEST GROUP	1	2	3	4	5	6
Runs	2, 10, 11	5, 6, 12	14, 15	3, 4	7, 9	13
Steam flow (lb/hr) (kg/hr)	44,000 20,000 (low)	61,600 28,000 (design)	62,400 28,400 (design)	61,500 28,800 (design)	70,000 31,800 (high)	69,500 31,600 (high)
Average excess air (%)	140	78	113	130	84	92
Average Radiation Temperature (°C)	864	1012	978	858	1046	997
(°F)	1587	1853	1792	1576	1915	1827
Average combustion air distribution (overfire/underfire)	60/40	63/35	90/10	60/40	60/40	60/40
Average CDD/CDF (ng/dscm)	191	64	550	660	174	300
Average CO (ppmv)	24	28	163	78	43	77

Figure 3-7 illustrates the reduction in emissions from the 1984 Environment Quebec test results.[30] Both of these tests measured stack emissions levels. Figure 3-8 compares the APCD inlet CDD/CDF emissions measured during the 1985 pilot study slipstream test with the test group averages from the parametric test. One important consideration when comparing these data is the effect of ESP temperatures on CDD/CDF stack emissions. The average stack temperature during the performance tests varied from 390 to 464°F (199 to 240°C). The extent to which catalytic formation reactions in the ESP contributed to the stack CDD/CDF emission levels is not known.

The modifications made at the Hampton and Quebec City MWCs addressed the same design, operating, and control features that were judged to be insufficient in the small mass burn waterwall model plant (mixing, air distribution, and control). The CDD/CDF stack emissions were reduced from 10,000-20,000 ng/dscm to 155 ng/dscm at Hampton and from 2000-4000 ng/dscm to 64 ng/dscm at Quebec (good combustion at design conditions). CO emissions were also reduced to 24 ppmv at Hampton and 28 ppmv at Quebec. Based on these data, it was assumed that the combustion retrofit specified for the model plant reduces CDD/CDF emissions from 2000 ng/dscm to 200 ng/dscm and reduces CO emissions from 400 ppmv to 50 ppmv (4-hour average). No change in inlet PM emissions is assumed to result from the modifications.

3.2 Refuse-Derived-Fuel Fired Spreader Stoker MWCs

There are 12 refuse-derived-fuel (RDF) fired plants currently operating in the U.S. Table 3-8 provides a list of operating plants and their individual design characteristics. Boiler sizes range from 300 to 1000 tpd (272 to 909 Mg/day) and the number of boilers at each facility location varies from 1 to 6. The oldest operating facility is the Akron, OH plant, which commenced operation in 1979. The majority of the systems are supplied by Detroit Stoker and B&W. Zurn, Combustion Engineering, and Foster Wheeler also have shares of the existing market. With the exception of the new B&W units at Biddeford, ME, which use a new pinched wall lower furnace, all the boilers are straight wall designs.

Nine of the 12 existing facilities are equipped with ESP controls and three plants use spray dryers and fabric filters. All three of the plants that currently use acid gas controls are less than 1 year old. Four of the

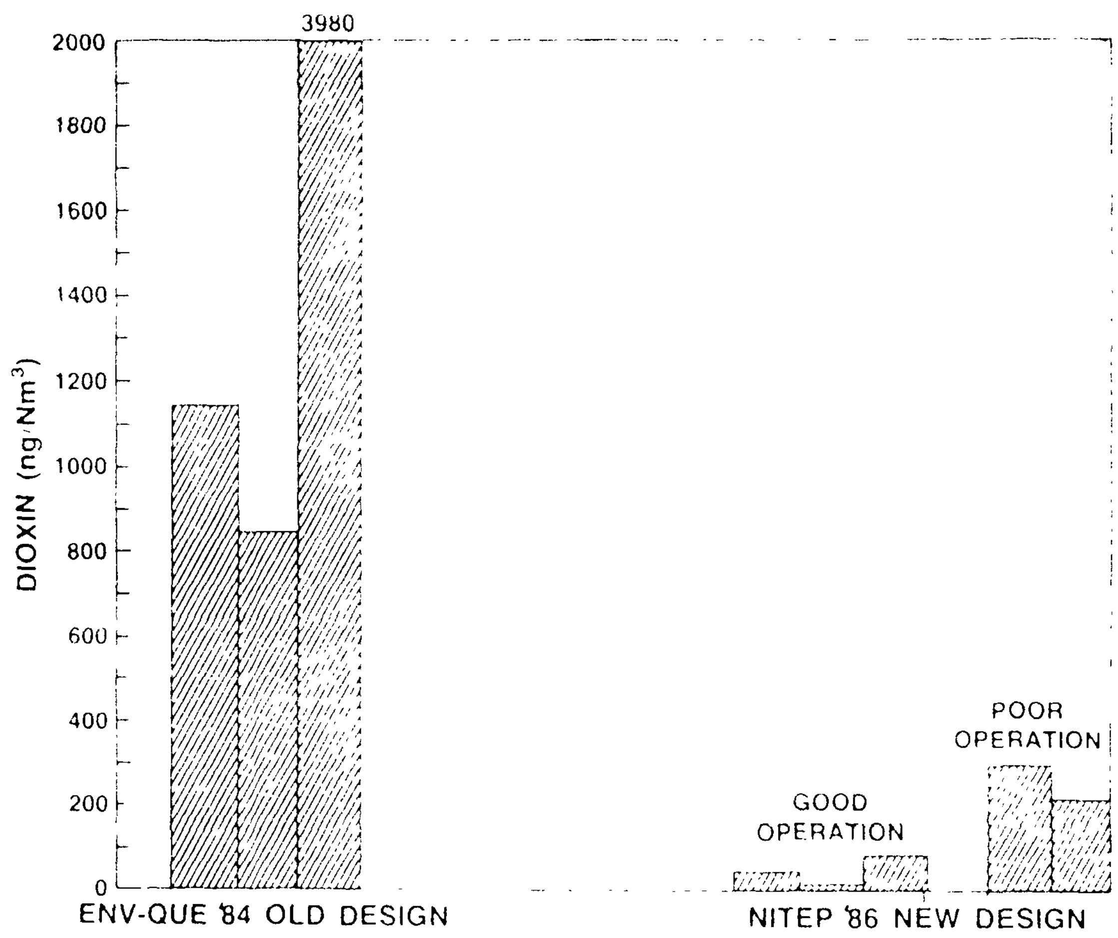

Figure 3-7. Comparison of Stack Test Results - Quebec City MWC.

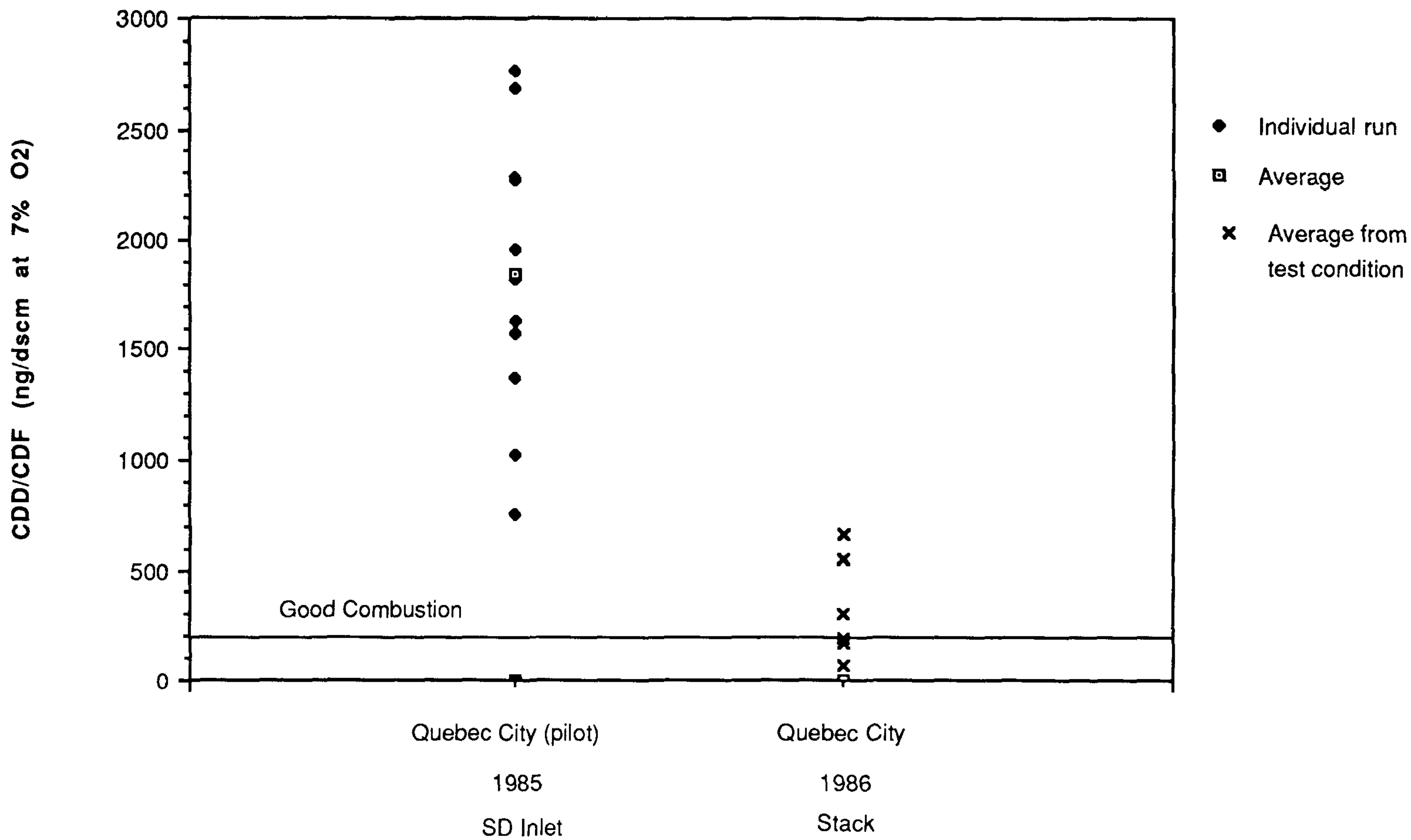

Figure 3-8. Combustion Control - Small Mass Burn Waterwall

TABLE 3-8. EXISTING RDF COMBUSTORS

PLANT LOCATION	MANUFACTURER STOKER/BOILER	# OF UNITS	INDIVIDUAL UNIT SIZE tpd	Mg/day	YEAR OF START-UP	APCD	ESP INLET TEMPERATURE °F	°C
Albany, NY	Zurn Zurn	2	300	272	1981	ESP	450	232
Niagara Falls, NY	Detroit Stoker Foster Wheeler	2	1000	909	1981	ESP	600	316
Dade County, FL	Detroit Stoker Fives Cail Babcock*	4	750	682	1982	ESP	310	154
Akron, OH	Detroit Stoker B&W	3	300	272	1979	ESP	525	273
Columbus, OH	Detroit Stoker B&W	6	400	364	1983	Cyclone/ ESP	608	320
Lawrence, MA	Detroit Stoker B&W	1	1000	909	1984	ESP	340	171
Red Wing, MN	Detroit Stoker Foster Wheeler‡	2	360	327	1987	ESP	420	216
Mankato, MN	Detroit Stoker B&W‡	2	360	327	1987	ESP	345	174
Portsmouth, VA	CE CE	4	480	436	1988	ESP	490	254
Biddeford, ME	Detroit Stoker B&W	2	350	318	1988	SD/FF	-	-
Orrington, ME	Detroit Stoker Riley	2	360	327	1988	SD/FF	-	-
Hartford, CT	CE CE	3	667	600	1988	SD/FF	-	-

*Undergoing modifications by Zurn. ‡Modified by B&W.

nine older plants with ESPs report normal ESP operating temperatures to be 475°F (246°C) or higher. All four of these plants are equipped with regenerative combustion air pre-heaters which are located downstream of the ESPs.

APCD inlet CDD/CDF emissions data are available from one facility (Biddeford, ME). Stack emissions data have been reported for five plants. One plant (Lawrence, MA) has measured CDD/CDF emissions data in the stack before and after undertaking a combustion retrofit program.

Table 3-9 summarizes the available emissions data from the existing population of RDF spreader stoker boilers. Also included in Table 3-9 is a summary of combustor design and operating practices for the units for which CDD/CDF data are available. Two model plants were developed to represent the majority of facilities in the existing population. The models represent large [≥600 tpd (545 Mg/day)] and small [<600 tpd (545 Mg/day)] combustor unit sizes. A discussion of the data used to establish baseline emission estimates is included below.

3.2.1 Albany, New York

The Albany, NY, RDF fired facility consists of two 300 tpd (272 Mg/day) spreader stoker boilers. The facility was tested by New York DEC in 1984. Six sampling runs were conducted in the stack (three while firing 100 percent RDF and three while co-firing natural gas with RDF). The natural gas contributed approximately 15 percent of the total heat input. The average CDD/CDF emissions were 440 ng/dscm while firing RDF and 840 ng/dscm during gas co-firing.[15] Particulate emissions at the ESP inlet are reported to be 4.18 gr/dscf (9610 mg/dscm). Continuous monitoring of combustion gases, including CO, O_2, and CO_2, was conducted during the sampling runs. Average CO emissions of 336 ppmv (4-hour average) were measured during the CDD/CDF test without gas firing. Very limited CO data are available during the MSW/gas firing tests, and there are no O_2 data available to allow correction to 7 percent O_2. However, the uncorrected CO data are in the same range as the CO emissions measured during the 100 percent RDF tests.

The natural gas burners are located on the rear wall approximately half way between the grate and the overfire air ports. It is suspected that the location of the burners may have contributed to the higher emission levels by

TABLE 3-9. RDF FIRED SPREADER STOKERS- PERFORMANCE ASSESSMENT
PAGE 1 OF 3

FACILITY		Albany, NY
NUMBER OF UNITS - FGC		2 - ESP
UNIT SIZE, tpd (Mg/day)		300 (272)
UNCONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)		NA
CO (ppmv)		NA
PM (mg/dscm)		9610
CONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)		432
CO (ppmv)		336

COMBUSTION PARAMETERS	GOOD COMBUSTION PRACTICE RECOMMENDATIONS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN		
Temperature at fully mixed height	1800°F (982°C) mean	1200°F (649°C) at inlet to convective section
Underfire air	As required for uniform bed stoichiometry	1 plenum
Overfire air capacity	40% total air	20% total air
Overfire air injector design	Coverage and penetration	Not used
Auxiliary fuel capacity	As required to achieve temperature limits during start-up	Gas - 100% load
Exit gas temperature	<450°F (232°C) at PM control device inlet	400-450°F (204-232°C)
OPERATION		
Excess air	3-9% O_2 (dry)	5.5-10%
Turndown	80-110% design load	50-100% of design
Overfire air	Penetration and coverage	Not achieved
Start-up procedures	Auxiliary fuel	Gas - 400°F (204°C) at ESP inlet
Auxiliary fuel use	High CO, low temp; start-up/shutdown	Start-up/shutdown
VERIFICATION		
O_2 levels	Monitor	Yes
CO	Monitor (<150 ppm at 7% O_2))	Yes
Temperature	Monitor	Yes
Air distribution	Monitor	NA
Exit gas temperature	Monitor	Yes

TABLE 3-9. RDF FIRED SPREADER STOKERS- PERFORMANCE ASSESSMENT
PAGE 2 OF 3

FACILITY	Niagara Falls, NY	Lawrence, MA
NUMBER OF UNITS - FGC	2 - ESP	1 - ESP
UNIT SIZE, tpd (Mg/day)	1000 (909)	1000 (909)
UNCONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	--	--
CO (ppmv)	204	--
PM (mg/dscm)	7480	--
CONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	4246	3304
CO (ppmv)	--	--
COMBUSTION PARAMETERS	FACILITY DESIGN AND OPERATING CONDITIONS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN		
Temperature at fully mixed height	1600°F (871°C) at inlet to convective section	NA
Underfire air	2 plenums with individual controls	NA
Overfire air capacity	45% of total air	At least 75% total air
Overfire air injector design	3 rows	NA
Auxiliary fuel capacity	Gas, oil, H2, coal - 100% load	Oil - Na
Exit gas temperature	600°F (316°C)	542°F (283°C)
OPERATION		
Excess air	10% O2	9.4% O2
Turndown	50-80% design load	NA
Overfire air	45% total air	75% total air
Start-up procedures	Gas to 1500°F (871°C) or 20% steam flow	NA
Auxiliary fuel use	Start-up; feed interruptions	NA
VERIFICATION		
O2 levels	Yes	Yes
CO	Yes	NA
Temperature	Yes	Yes
Air distribution	OFA/UFA pressures	Yes
Exit gas temperature	Yes	Yes

TABLE 3-9. RDF FIRED SPREADER STOKERS- PERFORMANCE ASSESSMENT
PAGE 3 OF 3

FACILITY	Biddeford, ME	Red Wing, MN
NUMBER OF UNITS - FGC	2 - SD/FF	2 - ESP
UNIT SIZE, tpd (Mg/day)	300 (272)	360 (318)
UNCONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	903	NA
CO (ppmv)	81	127
PM (mg/dscm)	8190	4900
CONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	--	28
CO (ppmv)	--	99
COMBUSTION PARAMETERS	FACILITY DESIGN AND OPERATING CONDITIONS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN		
Temperature at fully mixed height	NA	>1800°F (982°C) at inlet to first convective section
Underfire air	Metered fuel feeding	2 plenums
Overfire air capacity	60% total air	50% total air
Overfire air injector design		
Auxiliary fuel capacity	Gas - 40% load	100% load
Exit gas temperature	374°F (190°C)	260-450°F (127-232°C)
OPERATION		
Excess air	7% O2	7-11% O2
Turndown	40% minimum (on gas)	40% minimum
Overfire air	60% total air	50% at full load 20% at minimum load
Start-up procedures	Gas to 1800°F (982°C)	Gas
Auxiliary fuel use	Routinely co-fire, start-up, shutdown	Start-up
VERIFICATION		
O2 levels	Yes	Yes
CO	No	Yes
Temperature	Not currently measured	Yes
Air distribution	NA	Yes
Exit gas temperature	Yes	Yes

disrupting mixing patterns in the boiler and increasing vertical velocities of gases in the lower portion of the system. The ESPs reportedly operate near 450°F (232°C). Plant personnel reported during a site visit that the use of overfire air has been discontinued as a result of performance optimization tests.[1]

A review of design and operating practices at Albany indicates that the facility does not meet the recommended requirements for overfire air system design and operation. In addition, the traveling grate is a single speed stoker (not adjustable), and there is only one underfire air plenum.

3.2.2 Niagara Falls, New York

The Occidental Chemical Corporation RDF facility in Niagara Falls, NY comprises two 1000 tpd (909 Mg/day) spreader stoker boilers with four-field ESPs. The ESPs normally operate at 570 to 600°F (299 to 316°C). The plant was originally tested in 1985 by New York State. Stack CDD/CDF concentrations were reported to be 2561 ng/dscm and controlled PM emissions were 0.096 gr/dscf.[15] The ESPs were subsequently rebuilt and the system was retested. Particulate emissions were reduced to 0.012 gr/dscf; however, CDD/CDF emissions in the stack increased to 4246 ng/dscm.[30]

Several modifications have been made to the overfire air system in the last few years in an attempt to improve mixing. Based on review of the measured emissions, it appears that mixing and air distribution problems continue to exist despite the modifications. Slagging and corrosion problems have also led to higher excess air operating levels, which may contribute to high organics emissions as a result of quenching and increased PM carryover.[1] No ESP inlet CDD/CDF emissions are available for the facility, but it is judged that a portion of the CDD/CDF in the stack results from catalytic formation in the hot ESP. Average unabated particulate emissions were 3.25 gr/dscf (7580 mg/dscm) and CO emissions ranged from 200 to 250 ppmv, both corrected to 7 percent O_2.

3.2.3 Lawrence, Massachusetts

The Lawrence, MA, plant includes one RDF spreader stoker boiler rated at 1000 tpd (909 Mg/day) of RDF. The unit was tested in 1986 and CDD/CDF emissions in the stack were reported to be 3304 ng/dscm.[31] Like Niagara

Falls, the Lawrence facility was designed with a hot side ESP. The RDF boiler was operated at 83 to 87 percent of rated steam load during the test. The overfire airflow comprised more than 70 percent of the total air input to the system. The average flue gas temperature at the economizer was 542°F (283°C). There is insufficient information available on the design of the unit from which an assessment of its performance can be made relative to recommended good combustion practices. The unit was shut down voluntarily after the initial compliance test. A combustion retrofit was undertaken between 1986 and 1987, and the unit was brought on line again and retested in 1987. Stack CDD/CDF emissions were reduced to 111 ng/dscm.[32] No process operating data are included with the test results, and the details of the combustion retrofit have not been made public.

3.2.4 Biddeford, Maine

The Biddeford, ME, MWC was tested for CDD/CDF by EPA in December 1987. The plant comprises two boilers, each rated at 350 tpd (318 Mg/day) RDF. Emissions control on each unit is achieved by a cyclone, a spray dryer, and a baghouse. Emissions were measured at the spray dryer inlet (downstream of the cyclone) in conjunction with compliance testing performed in the stack. The unit that was tested was operating at full load during the test. Although an RDF/wood mixture is fired during normal operating conditions, 100 percent RDF was burned during the test. Three CDD/CDF sampling runs were performed and average unabated emissions were 903 ng/dscm.[33] Inlet particulate emissions were 3.56 gr/dscf (8190 mg/dscm), and average CO emissions were 81 ppmv. The boiler was operated at approximately 65-70 percent excess air during the test with an overfire/underfire ratio of 56/44. Each test run was 4 hours' duration. The average temperature at the spray dryer inlet location was 374°F (190°C).

3.2.5 Red Wing, Minnesota

The Red Wing facility comprises two 35-year-old coal-fired spreader stoker boilers that have been retrofitted to burn 100 percent RDF.[34] The boilers were enlarged by extending the furnace down into the basement, removing the coal bottom ash hoppers, lowering the stokers, and adding a 14-foot (4.3-m) waterwall extension fabricated from membrane panels with high nickel alloy weld overlay. The existing tube and tile upper furnace was connected to the new membrane walls by installation of a transition header. A new multilevel, multipoint, heated overfire air system was installed to ensure good mixing.

The facility was tested for CDD/CDF in 1987. Emissions at the ESP inlet were reported to be 60 ng/dscm, and average stack emissions were 28 ng/dscm.[35] Inlet particulate emissions were reported to be 2.13 gr/dscf (4900 mg/dscm), and average CO levels were 127 ppmv (5-hour average). The Red Wing units are designed to operate at 65 percent excess air with a 50/50 overfire/underfire air ratio. The average excess air level was 62 percent during CDD/CDF testing, and the air distribution was not specified. The design ESP inlet temperature is 420°F (216°C), and the average operating value was 425°F (218°C).

After the data were subjected to an EPA QA/QC review, the inlet CDD/CDF data were invalidated. Therefore, only the data measured in the stack were included in this analysis.

3.2.6 Baseline Emission Estimates

The two model plants representing existing RDF spreader stokers are distinguished mainly by size. The only major design feature that varied between the two model plants was the location and type of air heater. Based on the characteristics of the existing population, the large model plant was assumed to have a regenerative air heater located downstream of the ESP. The small model plant was assumed to use a tubular air heater located between the economizer and the ESP. Thus, the ESP on the large model plant is operated at a higher temperature, and it is judged that there is increased potential for catalytic formation of CDD/CDF in the control device.

The available emissions data used to establish baseline CDD/CDF emissions for RDF spreader stokers are plotted in Figure 3-9. The data from the Lawrence facility include only those emissions measured prior to the retrofit. The range of measured data varies greatly for all units in the population. There is no pattern in emissions that can be established based on unit size or manufacturer. There are facilities in the existing population which achieve many of the recommended good combustion practices for RDF spreader stokers. However, many plants in the population do not meet the criteria for good combustion, and the model plants are assumed to be more representative of these facilities. It is judged that the high CDD/CDF

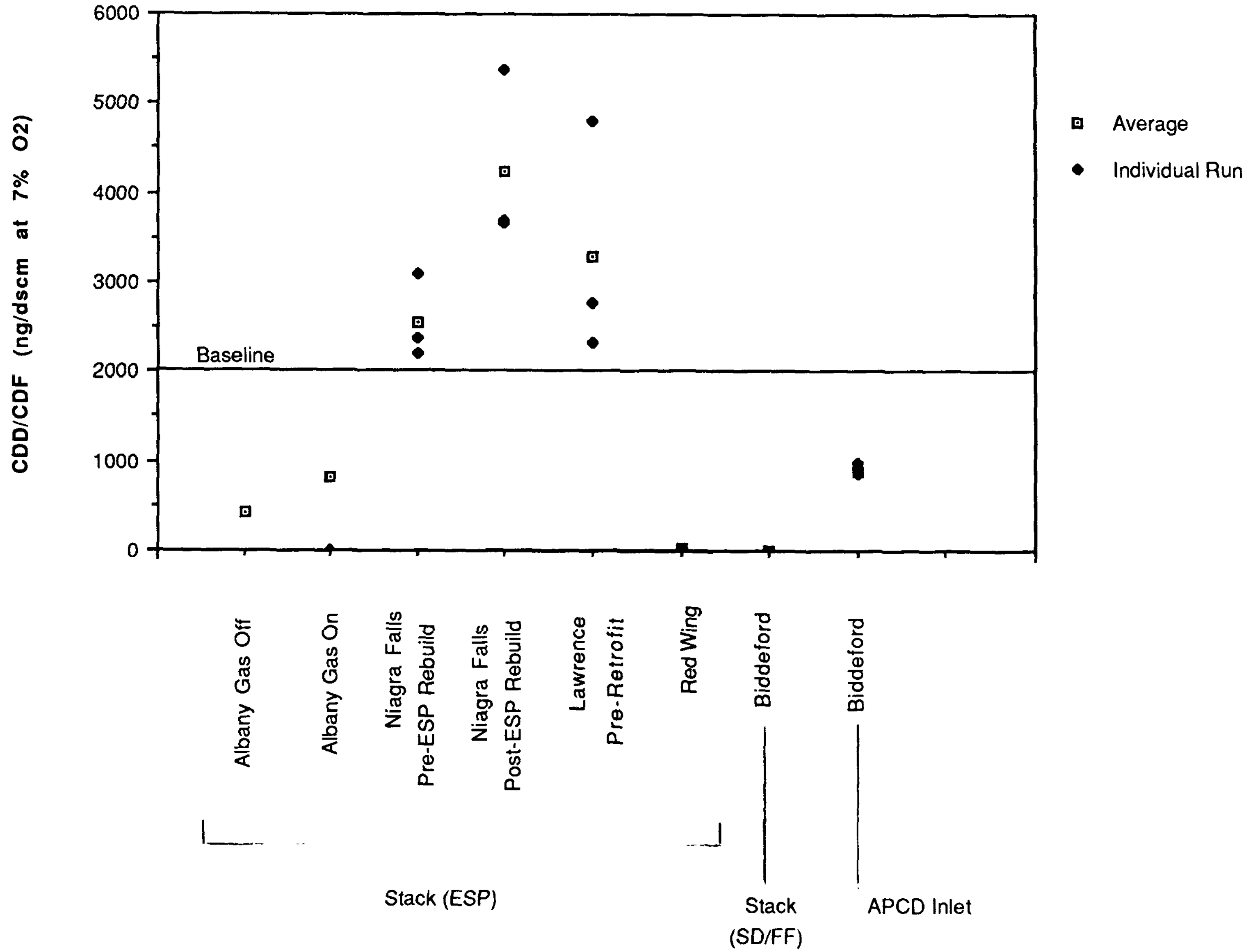

Figure 3-9. RDF Combustors Baseline Determination

emission levels at the Niagara Falls plant and the unmodified Lawrence facility are partly due to catalytic formation in the hot ESPs. The magnitude of the emissions increase is uncertain and cannot be determined using the available data. It was assumed in this analysis that the hot ESP contributes a net increase of CDD/CDF emissions of approximately 50 percent based on test data gathered at mass burn waterwall MWCs with hot ESPs.[8,9] Using this assumption, a baseline APCD inlet CDD/CDF emission rate of 2000 ng/dscm was established for both of the RDF spreader stoker model plants. The available CO emissions data base was used to establish a baseline CO emission level of 200 ppmv. The available PM emission data base was used to establish baseline emissions of 4 gr/dscf (9600 mg/dscm). Unabated PM emissions are typically higher from spreader stoker boilers than from other MWC technologies because of the semi-suspension firing mode.

3.2.7 Combustion Modifications

Fairly extensive modifications were recommended for each of the RDF model plants in order to bring their emission performance to levels representing good combustion practice. Both models required installation of metered feeding systems, redesigned overfire air systems, new automatic combustion controllers, and CO monitors for verification of good combustion. In addition, it was necessary to convert the hot ESP in the large RDF model to a cold side ESP by rearranging the ducting so that the flue gases enter the air heater prior to the ESP. It was estimated that the modifications at each model facility would reduce inlet CDD/CDF emissions from 2000 ng/dscm to 1000 ng/dscm and CO emissions from 200 ppmv to 150 ppmv.

The basis for the estimated emission reductions was formulated by using engineering judgement. It was judged that the recommended combustion modifications would reduce emissions to levels comparable to the Biddeford, ME plant, a new RDF fired facility.

3.3 Mass Burn Refractory Wall MWCs

The current population of mass burn refractory wall MWCs consists of 24 plants. Table 3-10 lists the facilities operating in 1988. Individual incinerator unit sizes vary from 88 to 375 tpd (80 to 341 Mg/day). The majority of the facilities are at least 15-20 years old. Three plants include relatively new units: the Tampa, FL plant commenced operation in 1985 using

TABLE 3-10. EXISTING MASS BURN REFRACTORY WALL COMBUSTORS

PLANT LOCATION	GRATE TYPE	# OF UNITS	INDIVIDUAL UNIT SIZE tpd	Mg/day	YEAR OF START-UP	APCD	ESP INLET TEMPERATURE °F	°C
<u>Batch Feed</u>								
Stamford I, CT		1	150	136	1953	ESP	NA*	NA
Huntington, NY		2	150	136	NA	Water sprays	-	
<u>Continuous Feed</u>								
Philadelphia NW, PA	Traveling	2	375	341	1957	ESP	550	288
Philadelphia EC, PA	Traveling	2	375	341	1965	ESP	550	288
E Chicago, IN	Traveling	2	225	205	1971	Venturi scrubber	-	-
SE Oakland County, MI	Traveling	2	300	272	1965	Venturi scrubber	-	-
Honolulu, HI	Traveling	2	300	272	1970	ESP	450	209
New York, NY (Betts Ave)	Traveling	4	250	227	1960	ESP	550	288
Clinton, MI	Reciprocating	2	300	272	1972	ESP	500	254
Euclid, OH	Reciprocating	2	100	91	1955	ESP	550	288
Fall River, MA	Reciprocating	2	300	272	1972	Wet scrubber	-	-
New Canaan, CT	Reciprocating	1	125	114	1971	Venturi scrubber	-	-
Washington, DC	Rocking	4	250	227	1972	ESP	500	254
Baltimore. MD (Pulaski)	Reciprocating	4	300	272	1954	ESP	500-600	254-316
SW Brooklyn, NY	Reciprocating	4	240	218	1959	ESP	NA	NA
Waukesha, WI	Reciprocating	2	88	80	1971	ESP	450	209
Stamford II, CT	Rocking	1	360	327	1974	ESP	NA	NA
Sheboygan, WI	Rocking	2	120	109	1965	Water sprays	-	-
Huntington, NY	Rocking	1	150	136	1963	ESP	NA	NA
N Dayton, OH	Grate/rotary kiln	3‡	300	272	1970 1988	ESP	600	316
S Dayton, OH	Grate/rotary kiln	3†	300	272	1970 1988	ESP	600	316
Louisville, KY	Grate/rotary kiln	4	250	227	1956	Wet scrubber	-	-
Framingham, MA	Grate/rotary kiln	2	250	227	1973	Dry scrubber/FF	-	-
Tampa, FL (McKay Bay)	Grate/rotary kiln	4	250	227	1985	ESP	550	288

*NA - Information not available. ‡This plant has recently added a third unit of similar design, with heat recovery. †This plant has recently added a third unit of similar design.

four 250 tpd (227 Mg/day) Volund combustors with waste heat recovery boilers. Facility expansions have occurred at two plants (North and South Montgomery County, OH), with installation of a third 300 tpd (272 Mg/day) combustor at each location in 1988. The North plant was constructed with a waste heat recovery boiler and the South plant provided space for a future boiler installation.

Four distinct design types are used in the existing population. The first and oldest design is a batch fed unit which is in place at two locations (Stamford, CT and Huntington, NY). At one time the population included many of these systems, but most have been closed in the last two decades.

A second design type is the rectangular incinerator with traveling grates. There were six facilities of this type identified in the existing population, although two plants in Philadelphia (Northwest and East Central) and the plant in Southeast Oakland County, MI were permanently shut down in 1988. These closures reduce the number of existing plants using this design to three.

A third design also uses a rectangular incinerator similar in configuration to the second type, but this design uses rocking or reciprocating grates to agitate the burning waste bed as it moves through the incinerator. This feature improves the ability of the combustor to achieve waste burnout. Eleven plants of this type have been identified in the existing population.

The last combustor design uses a split flow configuration with reciprocating grates and a rotary kiln. There are five plants of this type, one of which is Tampa, FL, a relatively new Volund design. The other plants are early vintage Volund units or adaptations thereof.

Sixteen of the existing MWCs use ESPs for particulate removal. Due to the high gas temperatures leaving a non-heat recovery facility, wet quench systems are always in place to reduce gas temperatures before they enter an ESP. Seven existing plants use wet controls (spray chamber, venturi scrubbers, or impingement scrubbers) without additional PM controls. One facility in Framingham, MA is equipped with a spray dryer and fabric filters. Review of available information related to flue gas temperatures indicates that at least 10 facilities (32 units) operate ESPs at temperatures between 500 and 600°F (260 and 316°C).

3.3.1 Emissions Data

3.3.1.1 Philadelphia NW and EC, Pennsylvania

The available CDD/CDF emissions data from mass burn refractory wall MWCs are limited to test results from only 1 of the 24 plants in Table 3-10. Both units at the Philadelphia NW plant were tested for CDD/CDF in 1985 under normal operating conditions. Three sampling runs were conducted for CDD/CDF in the stack, downstream of the wet quench/ESP control system. Average CDD/CDF emissions were reported to be 5923 ng/dscm from Unit #1 and 5915 ng/dscm from Unit #2.[36] Only two runs are included in the average for Unit #1 because a low surrogate sample recovery was reported for one run. The sampling runs and average values are presented graphically in Figure 3-10. Results of CO monitoring performed during the test indicated average emissions of 447 ppmv at Unit #1 and 821 ppmv at Unit #2. The units do not produce steam or monitor feed rates directly. Continuous O_2 monitors in the stack indicated that the units operated an excess air level ranging from 180 to 260 percent during the test. During a visit to the facility, numerous points of air inleakage were observed in the system.[1] The stack gas temperature ranged from 508 to 515°F (265 to 269°C) at Unit #1 and 503 to 518°F (262 to 270°C) at Unit #2. Carbon monoxide emissions were also measured at the Philadelphia East Central (EC) plant, which is similar in design and identical in capacity to the Northwest facility. Average CO emissions from the two EC units were reported to be 140 and 51 ppmv, respectively.[36] Excess air levels during testing were approximately 275 percent at Unit 1 and 390 percent at Unit #2. There are no additional process data available.

3.3.1.2 Foreign Data

Data summaries are reported for several other refractory wall incinerators in the MWC Emissions Data Base Volume of the Report to Congress. Although there is limited documentation for most of the emission values, the data are comparable to the stack values reported for Philadelphia NW. Stack emissions reported for four plants (Toronto, Ontario; Braschatt, Belgium; Harelbeke, Belgium; and Zaanstad, Netherlands) vary from 5320 to 6850 ng/dscm.[23] Emission control device temperatures are not available for these data sets.

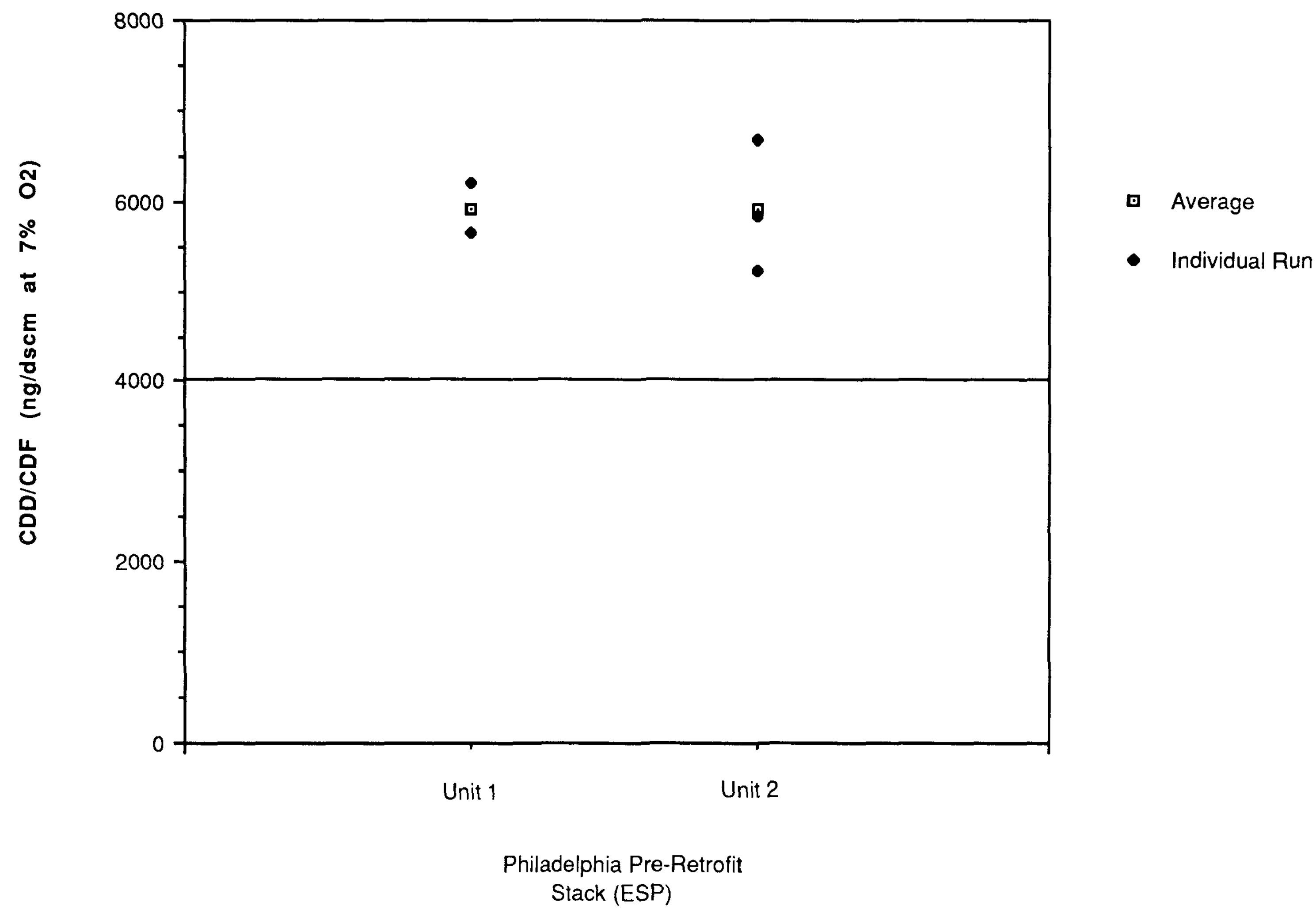

Figure 3-10. Mass Burn Refractory Baseline Determination

3.3.2 Baseline Emission Estimates

Three model plants were developed to represent the existing population of mass burn refractory wall MWCs. The model configurations include two rectangular combustors, one with traveling grates and one with rocking grates, and one split flow design with grates and a rotary kiln. None of the model plants incorporates heat recovery into its design. Due to the limited availability of emissions data from mass burn refractory wall combustors, a single baseline emission level was established for the three model plants.

Comparing the emissions data from Philadelphia NW to those data gathered from foreign plants, it appears that the majority of existing refractory wall MWCs could potentially have high emissions. The majority of refractory wall incinerators were designed with a primary goal of waste volume reduction, and concerns regarding levels of trace organic emissions did not exist at the time they commenced operation. The recommended good combustion practices for mass burn refractory wall MWCs require good mixing at adequate temperatures for thermal destruction of trace organic compounds, and minimization of conditions that may cause formation of these compounds in low temperature regions of the system. None of the existing mass burn refractory wall model MWCs meets both of these criteria.

The ESP operating temperature at the Philadelphia units [550°F (288°C)] likely contributes to the high CDD/CDF emission values. It is assumed that formation of CDD/CDF in the ESP accounts for a 50 percent increase over the uncontrolled emission values. Therefore, uncontrolled baseline CDD/CDF emissions are assumed to be 4000 ng/dscm. Average carbon monoxide emissions data from Philadelphia NW and Philadelphia EC vary from 51 to 821 ppmv. A conservative average of 500 ppmv was assumed as a baseline CO emission level. Inlet PM emissions are assumed to be 3 gr/dscf (6900 mg/dscm). Baseline APCD inlet PM emissions for the mass burn waterwall models are 2 gr/dscf (4600 mg/dscm). Waterwall plants usually operate at 80-100 percent excess air. The refractory wall models operate at 200-300 percent excess air in the baseline condition. It is assumed that higher airflows will contribute to increased carryover of particulate from the combustor.

3.3.3 Combustion Modifications

The basis for the estimated emission reductions applied to the refractory wall model plants comes from test data gathered at Philadelphia NW. The plant was retested in December 1987 after modifying the configuration of the upper combustion chamber to increase flue gas residence time. Refractory lined structural steel arches were installed to improve mixing of flue gases in the upper combustion chamber. In addition, the location of the existing water quench sprays was moved 25 feet (7.6 m) downstream in the furnace discharge breeching to provide increased residence time at high temperatures. Average stack CDD/CDF emissions were reduced to 1000 ng/dscm.[37] Figure 3-11 compares the 1987 and the 1985 CDD/CDF emissions data reported for the two units at Philadelphia NW. The ESP operating temperature was not reduced as part of the modification. Therefore, it is judged that the ESP inlet CDD/CDF emissions are lower than 1000 ng/dscm.

The proposed modifications for the three model plants are far more extensive than those made at Philadelphia NW. They include changes in furnace geometry; excess air rates and air distribution; modifications to combustion control systems; and, in the case of the traveling grate model, replacement of the stokers with reciprocating grates. It is judged that the combined effects of these modifications will enable the three model plants to achieve CDD/CDF emissions of 500 ng/dscm at the APCD inlet.

Reduction of excess air levels and improved mixing will also contribute to lower CO emissions. It is assumed that the combustion modifications, which include reducing excess air levels and improving mixing, will reduce CO emissions to 150 ppmv. No other changes in emissions are assumed to occur as a result of the modifications.

3.4 Mass Burn Modular Starved Air MWCs

There are nearly 50 modular starved air plants in the existing MWC population. Table 3-11 presents a list of these facilities. Individual combustor capacities range from 5 to 90 tpd (4.5 to 82 Mg/day), with one to four units per facility location. The facilities range in age from new to 17 years. Thirty-one of the 49 existing plants in Table 3-11 use heat recovery boilers, and the remainder are simply waste volume reduction plants. Most of the larger, newer facilities are equipped with add-on air pollution control,

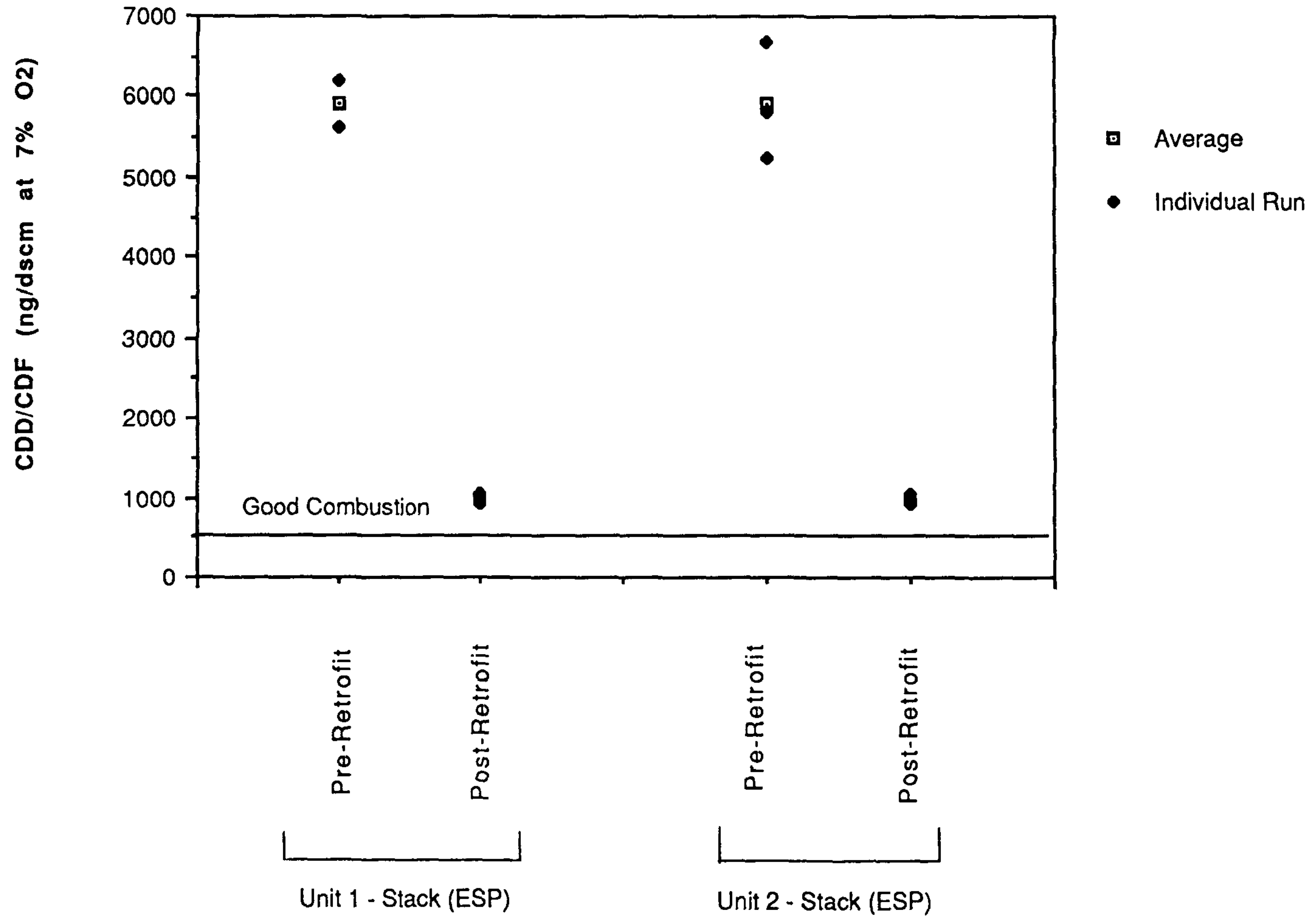

Figure 3-11. Combustion Control - Refractory

TABLE 3-11. EXISTING MODULAR STARVED AIR COMBUSTORS
page 1 of 2

PLANT LOCATION	# OF UNITS	UNIT SIZE tpd	UNIT SIZE Mg/day	YEAR OF START-UP	HEAT RECOVERY	APCD	INLET TEMPERATURE °F	INLET TEMPERATURE °C
CONSUMAT SYSTEMS								
Bellingham, WA	2	50	45	1986	yes	none	-	-
Auburn, NH	1	5	4.5	NA	no	none	-	-
Wolfboro, NH	2	8	7.3	1975	no	none	-	-
Litchfield, NH	1	22	20	NA	no	none	-	-
Newport News, VA	1	35	32	1980	yes	none	-	-
Carthage, TX	1	36	33	1985	yes	none	-	-
Center, TX	1	36	33	1985	yes	none	-	-
Batesville, AR	1	50	45	1981	yes	none	-	-
Cassia County, ID	2	25	23	1982	yes	none	-	-
Johnsonville, SC	1	50	45	NA	yes	ESP	NA	NA
Osceola, AR	2	25	23	1980	yes	none	-	-
Wrightsville Beach, NC	2	25	23	1981	no	none	-	-
Red Wing, MN	2	45	41	1982	yes	ESP	550	288
Livingston, MT	2	38	35	1982	yes	none	-	-
Barron County, WI	2	40	36	1986	no	ESP	425	218
Dyersburg, TN	2	50	45	1980	yes	none	-	-
Salem, VA	4	25	23	1977	yes	none	-	-
N Little Rock, AR	4	25	23	1977	yes	none	-	-
Durham, NH	3	36	33	1980	yes	cyclone	NA	NA
Miami, OK	3	35	32	1982	yes	none	-	-
Windham, CT	3	36	33	1981	yes	none	-	-
Oswego, NY	4	50	45	1986	yes	ESP	450	232
Auburn, ME	4	50	45	1981	yes	fabric filter	550-600	288-316
Portsmouth, NH	4	50	45	1982	yes	fabric filter	NA	NA
Hampton, SC	3	90	82	1985	yes	ESP	NA	NA
Harford County, MD	4	90	82	1987	yes	ESP	NA	NA
Wilton, NH	1	30	27	1978	no	none	-	-
Stuttgart, AR	3	23	21	1971	no	none	-	-
Tuscaloosa, AL	4	75	68	1984	yes	ESP	450	232
Coos Bay, OR	2	12.5	11	1978	no	none	-	-
	2	50	45	1980	no	none	-	-

TABLE 3-11. EXISTING MODULAR STARVED AIR COMBUSTORS
page 2 of 2

PLANT LOCATION	# OF UNITS	UNIT SIZE tpd	UNIT SIZE Mg/day	YEAR OF START-UP	HEAT RECOVERY	APCD	INLET TEMPERATURE °F	INLET TEMPERATURE °C
CONSUMAT SYSTEMS (cont'd)								
Blytheville, AR	2	36	33	1983	no	none	-	-
Juneau, AK	2	35	32	1985	no	ESP	800	427
Brookings, OR	2	24	21	1979	no	none	-	-
Windham, ME	2	22	20	1975	no	none	-	-
KELLY SYSTEMS								
Canterbury, NH	1	10	9.2	NA	no	none	-	-
Candia, NH	1	15	14	1979	no	none	-	-
Meredith, NH	2	15	14	NA	no	none	-	-
Pittsfield, NH	1	48	44	NA	no	none	-	-
ECP SYSTEMS								
Groveton, NH	1	24	21	1980	yes	none	-	-
Fort Leo. Wood, MO	3	26	24	1982	yes	none	-	-
CLEAR AIR/SYNERGY								
Fort Dix, VA	4	20	18	1986	yes	FF/VWS/ packed tower	-	-
Perham, MN	2	57	52	1986	yes	ESP	425	218
Waxahachie, TX	2	25	23	1982	yes	none	-	-
Cattaraugus, NY	3	38	35	1983	no	none	-	-
Oneida County, NY	4	50	45	1985	yes	ESP	400-470	204-243
JOHN ZINK								
Westmoreland County, PA	2	25	23	1986	yes	ESP	480	249
Fergus Falls, MN	2	38	35	1988	yes	WS/Venturi	-	-
Polk County, MN	2	40	36	1988	yes	ESP	475	246
SUNBEAM								
Pelham, NH	2	24	21	1987	no	none	-	-

although older plants, less than 50 tpd (45 Mg/day), typically do not have APCDs. Only 17 plants reportedly use add-on controls, and the majority of these are ESPs. Two existing facilities report ESP operating temperatures in the 500-600°F (260-316°C) range.

Thirty-four of the existing plants are Consumat designs, which use transfer rams in the primary chamber for waste movement. The Clear Air designs use reciprocating grates, and the other designs are similar to Consumat. The Clear Air systems also typically operate with slightly higher temperatures in the primary chamber than the Consumat units, typically 1600-1800°F (871-982°C) versus 1400-1600°F (760-871°C).

3.4.1 Emissions Data

Emissions of CDD/CDF have been reported for four existing facilities. Stack emissions are available from Cattaraugus County, NY and Charlottetown, PEI. Both of these plants have no add-on controls. Stack emissions are reported from Oneida County, NY and Red Wing, MN. Cattaraugus County and Oneida County are Clear Air units, and the two others are Consumat designs. The available emissions data are presented in Table 3-12 along with a summary of individual plant design and operating practices. More information on individual emission tests is presented below.

3.4.1.1 Prince Edward Island

Emissions testing was performed at PEI at four operating conditions (normal, long feed cycle, high secondary chamber temperature, and low secondary chamber temperature). The facility consists of three Consumat CS-1600 combustors, each rated at 36 tpd (33 Mg/day). The combustors exhaust to a common waste heat recovery boiler and then to a stack without further emissions control. A process schematic of the facility is provided in Figure 3-12. Sampling was performed at the boiler inlet location and in the stack. The primary operating variables were primary and secondary combustion temperatures and feed cycle. Three sampling runs were performed for each condition. The average CDD/CDF and CO data are presented in Table 3-13 for each operating condition.[6]

The data in Table 3-13 indicate that CDD/CDF emission levels in the stack are partially due to formation that occurs in the lower temperature

TABLE 3-12. MODULAR STARVED AIR MWCS - PERFORMANCE ASSESSMENT
PAGE 1 OF 3

FACILITY		Prince Edward Island
NUMBER OF UNITS - FGC		3 - None
UNIT SIZE, tpd (Mg/day)		36 (33)
<u>UNCONTROLLED EMISSIONS</u>		
CDD/CDF (ng/dscm)		409
CO (ppmv)		62
PM (mg/dscm)		225
<u>CONTROLLED EMISSIONS</u>		
CDD/CDF (ng/dscm)		--
CO (ppmv)		--
COMBUSTION PARAMETERS	GOOD COMBUSTION PRACTICE RECOMMENDATIONS	FACILITY DESIGN AND OPERATING CONDITIONS
<u>DESIGN</u>		
Temperature at fully mixed height	1800°F (982°C) average	1832°F (1000°C) (secondary chamber)
Secondary air capacity (not an operating requirement)	80% total air	NA
Secondary air injector design	That required for penetration and coverage	NA
Auxiliary fuel capacity	As required to achieve temperature limits during start-up	NA
Exit gas temperature	<450°F (232°C) at PM control device inlet	363°F (184°C)
<u>OPERATION</u>		
Excess air	6-12% O_2 (dry)	12% O_2
Turndown	80-110% design load	NA
Secondary air	80% total air	NA
Start-up procedures	On auxiliary fuel to design temperature	NA
Auxiliary fuel use	High CO, low temp; start-up/shutdown	NA
<u>VERIFICATION</u>		
O_2 levels	Monitor	No
CO	Monitor (<50 ppm at 7% O_2))	No
Temperature	Monitor	Primary and secondary chamber
Air distribution	Monitor	No
Exit gas temperature	Monitor	No

TABLE 3-12. MODULAR STARVED AIR MWCS - PERFORMANCE ASSESSMENT
PAGE 2 OF 3

FACILITY	Cattaraugus County, NY	Oneida County, NY
NUMBER OF UNITS - FGC	3 - None	4 - ESP
UNIT SIZE, tpd (Mg/day)	38 (35)	50 (45)
UNCONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	345	--
CO (ppmv)	NA	--
PM (mg/dscm)		
CONTROLLED EMISSIONS		
CDD/CDF (ng/dscm)	--	462
CO (ppmv)	--	--

COMBUSTION PARAMETERS	FACILITY DESIGN AND OPERATING CONDITIONS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN		
Temperature at fully mixed height	1800-2000°F (983-1093°C) (secondary exit)	1800°F (983°C) (secondary exit)
Secondary air capacity (not an operating requirement)	At least 40% total air	NA
Secondary air injector design	NA	NA
Auxiliary fuel capacity	Gas - 30% load	Gas - 100% (not used)
Exit gas temperature	502°F (216°C) (stack)	400-450°F (204-232°C) (boiler outlet)
OPERATION		
Excess air	NA	NA
Turndown	NA	NA
Secondary air	40% of total air	NA
Start-up procedures	On gas to 1800°F (983°C) in secondary	Not used
Auxiliary fuel use	Start-up	None
VERIFICATION		
O2 levels	No	No
CO	No	No
Temperature	Primary and secondary chamber	Primary and secondary chamber
Air distribution	Primary air	No
Exit gas temperature	Yes	Yes

TABLE 3-12. MODULAR STARVED AIR MWCS - PERFORMANCE ASSESSMENT
PAGE 3 OF 3

FACILITY	Red Wing, MN
NUMBER OF UNITS - FGC	2 - ESP
UNIT SIZE, tpd (Mg/day)	45 (41)
UNCONTROLLED EMISSIONS	
CDD/CDF (ng/dscm)	--
CO (ppmv)	--
PM (mg/dscm)	--
CONTROLLED EMISSIONS	
CDD/CDF (ng/dscm)	3358
CO (ppmv)	2

COMBUSTION PARAMETERS	FACILITY DESIGN AND OPERATING CONDITIONS
DESIGN	
Temperature at fully mixed height	1800°F (983°C) (secondary exit)
Secondary air capacity (not an operating requirement)	NA
Secondary air injector design	
Auxiliary fuel capacity	Gas - NA
Exit gas temperature	550-600°F (288-316°C)
OPERATION	
Excess air	10-12% 02
Turndown	NA
Secondary air	MA
Start-up procedures	Gas - not used
Auxiliary fuel use	Not used
VERIFICATION	
02 levels	Yes
CO	No
Temperature	Primary and secondary chamber
Air distribution	No
Exit gas temperature	Yes

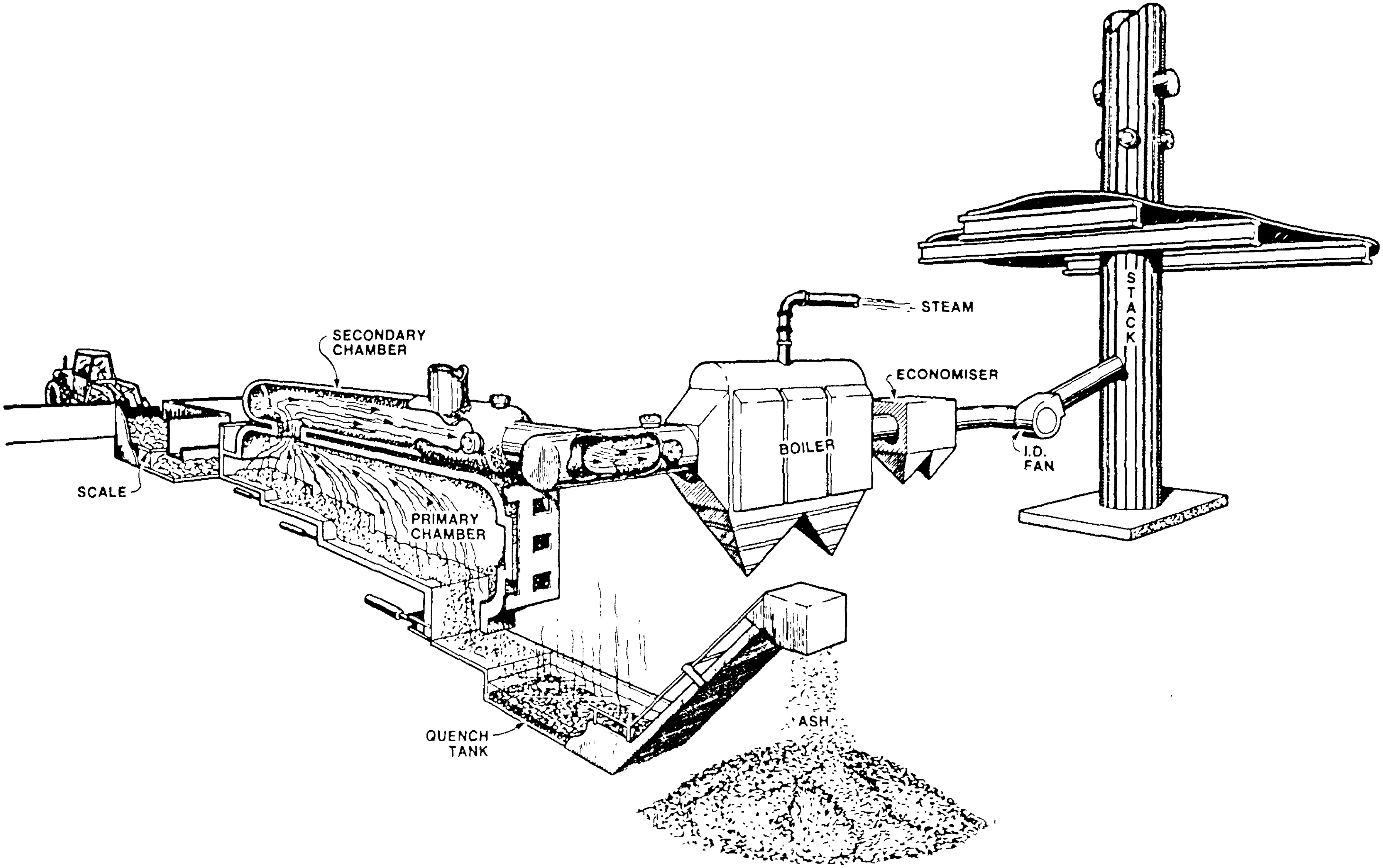

Figure 3-12. Prince Edward Island MWC.

TABLE 3-13. PERFORMANCE TEST DATA
PRINCE EDWARD ISLAND MWC

	BOILER INLET			STACK			
CONDITION	CDD/CDF (ng/dscm)	TEMPERATURE °F	TEMPERATURE °C	CDD/CDF (ng/dscm)	CO (ppmv)	TEMPERATURE °F	TEMPERATURE °C
Normal	NA	1544	840	409	62	363	184
Long Cycle	0	1544	840	441	39	363	184
High Secondary	1	1922	1050	198	38	361	183
Low Secondary	42	1364	740	424	53	266	130

portions of the system. With the exception of the low secondary temperature conditions, CDD/CDF emissions are near zero at the boiler inlet. The higher emission levels during the low secondary temperature condition likely results from insufficient temperatures to provide destruction of CDD/CDF and precursors. Secondly, the operating variable that had the most noticeable effect on CDD/CDF stack emissions was the high secondary chamber temperature. These data provide support for the combustion temperature requirements in the MWC recommendations.

3.4.1.2 Cattaraugus County, New York

The second set of CDD/CDF emissions data was gathered at the Clear Air facility in Cuba (Cattaraugus County), NY. The plant consists of three 38 tpd (35 Mg/day) units that began operating in 1983. The plant has heat recovery but uses no flue gas cleaning device. Two CDD/CDF sampling runs are available from testing performed by New York State DEC in 1984, and average emissions were reported to be 345 ng/dscm.[15] There are no CO data available with the test results. Primary chamber temperatures were approximately 2200-2300°F (1204-1260°C) and secondary chamber temperatures were maintained near 2000°F (1093°C) during testing.

3.4.1.3 Oneida County, New York

Oneida County is another Clear Air facility which comprises four units at 50 tpd (45 Mg/day) each. The plant has heat recovery in place and is equipped with an ESP. Stack testing was performed by New York State DEC in 1985. Average CDD/CDF emissions at Unit #1 were 462 ng/dscm.[15] The temperature at the ESP inlet was 458°F (237°C). Primary chamber temperatures were approximately 1600-1800°F (871-982°C) and secondary chamber temperatures were 1700-2000°F (927-1093°C) during testing.

3.4.1.4 Red Wing, Minnesota

The Red Wing, MN facility includes two 45 tpd (41 Mg/day) Consumat units with a waste heat boiler and ESP controls. The facility was sampled for CDD/CDF and other pollutants in the stack in September 1986. The available process data indicate that temperatures ranged from 1400 to 1600°F (760 to 871°C) in the primary chambers and 1750 to 1960°F (954 to 1071°C) in the secondary chamber. These temperatures are typical for Consumat designs in general, and in the same range as those measured at the other Consumat systems that achieved low CDD/CDF emissions. The average CO data were also extremely low (<2 ppmv), indicating good combustion in the primary and secondary chambers. However, average CDD/CDF emissions in the stack were 3358 ng/dscm.[38] The ESP operated at a temperature of 590-600°F (310-316°C) during the tests. It is judged that the high CDD/CDF emissions in the stack result from formation in the ESP.

3.4.2 Baseline Emission Estimates

The available emissions data provide evidence that relatively low CDD/CDF concentrations can be achieved by modular starved air MWCs. The key conditions that lead to low emissions are the same as specified for other technologies: achieve good mixing at adequate temperature and minimize the conditions that lead to downstream formation of CDD/CDF. Starved air MWCs can achieve adequate secondary chamber temperatures by control of air flows. The fully mixed location in a modular starved air MWC can be defined at the exit of the secondary combustion chamber. The available data also indicate that total elimination of downstream formation of CDD/CDF may not be feasible. However, systems should be designed and operated in a manner which minimizes the potential for these occurrences. The emissions data used to establish baseline emissions for the model plants are presented in Figure 3-13. Based on the available data from Cattaraugus, Oneida, and PEI, baseline CDD/CDF emissions were assumed to be 400 ng/dscm. The Red Wing data were not used to support baseline emissions because the high emission levels are suspected to result from formation in the ESP, and the emission levels upstream of the ESP are unknown. Based on the average CO emissions of 62 ppmv measured at PEI, baseline CO emissions are assumed to be 100 ppmv. Baseline PM emissions were established at 0.15 gr/dscf (345 mg/dscm) using data from PEI. The baseline emissions were applied to both of the modular starved air model plants.

3.4.3 Combustion Modifications

Modifications required for the model plants included installation of continuous monitors for verification of O_2 and CO operating levels. In addition, an economizer was added to the larger model to reduce flue gas temperatures entering the ESP. Although the modifications did not change uncontrolled emission levels, stack CDD/CDF emissions were reduced by lowering

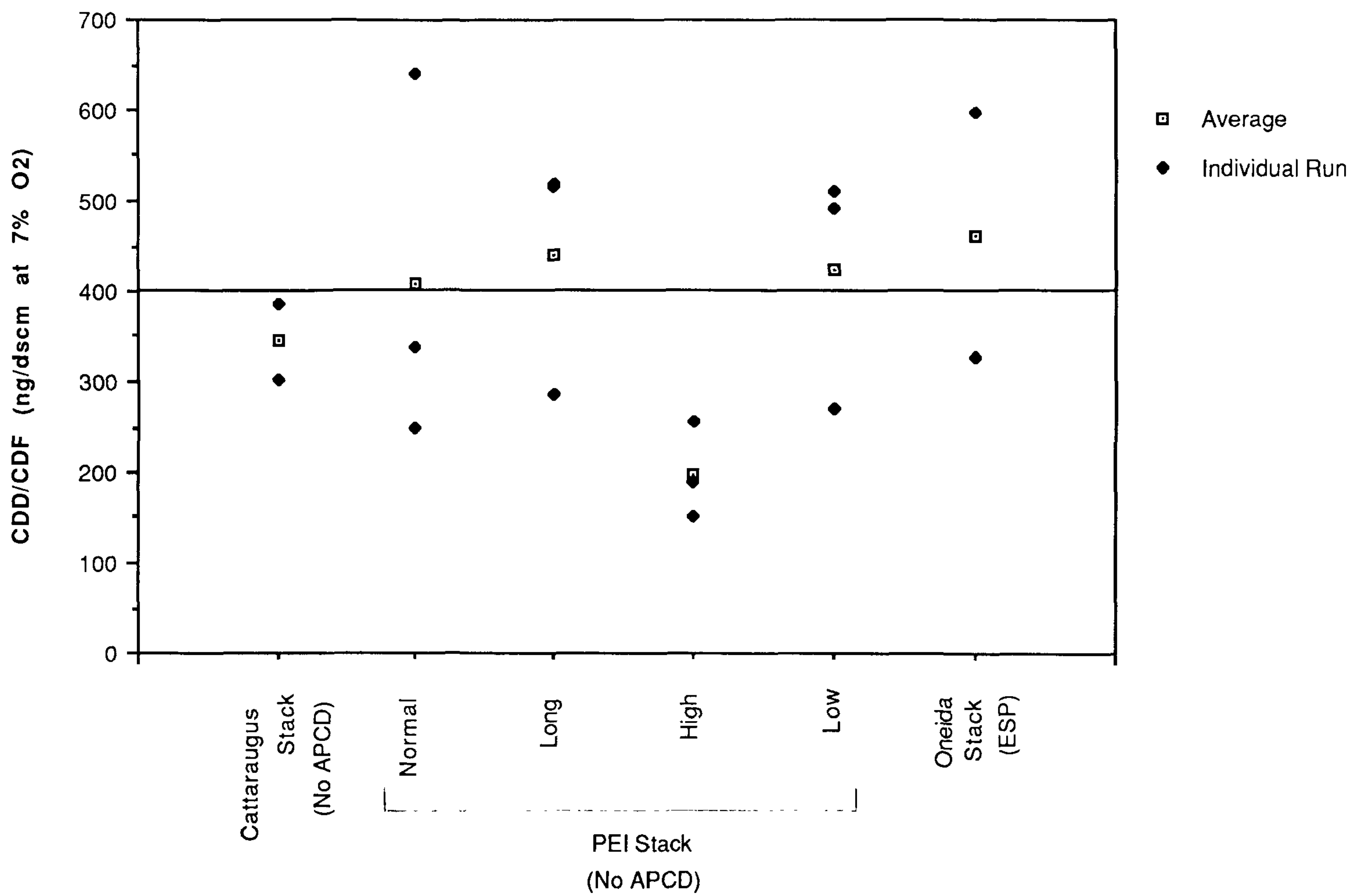

Figure 3-13. Mass Burn Modular Starved Air Baseline Determination

ESP operating temperatures, thus preventing CDD/CDF formation in the control device.

3.5 Mass Burn Modular Excess Air MWCs

Sixteen existing facilities comprise the population of mass burn modular excess air MWCs. Table 3-14 presents a list of these plants. Unit sizes vary from 8 to 120 tpd (7.3 to 109 Mg/day), with one to five combustors per facility location. The existing population includes some very different designs, including Vicon/Enercon, Cadoux, and Sigoure Freres. A decision was made in the Retrofit Study to develop a model plant based on the Vicon/Enercon design. There are 3 existing plants of this design type, and these 3 plants have a greater total capacity than the other 13 existing plants combined. The Vicon/Enercon units incorporate some very distinct design features, including a tertiary duct where burnout of combustion gases occurs, and extensive use of flue gas recirculation (FGR). A complete description of an operating facility is included in the MWC Retrofit Study.[1]

3.5.1 Emissions Data

3.5.1.1 Pittsfield, Massachusetts

There are three sets of CDD/CDF data available from modular excess air MWCs. The first data set includes the parametric test results obtained from a research program conducted at the Vicon/Enercon facility in Pittsfield, MA.[7] A facility equipment schematic is shown in Figure 3-14. The plant comprises three 120 tpd (109 Mg/day) units and two waste heat boilers. Testing was performed with two of the three units in operation, which is the normal operating condition for the facility. Each boiler exhausts to an electrified granular bed (EGB) filter for removal of PM. The EGBs typically operate at 475°F (246°C). Organic emissions, including CDD/CDF, PCBs, chlorophenols, and chlorobenzenes, were measured over a large range of operating conditions and while firing various fuels (MSW, PVC spiked MSW, PVC free waste).

Table 3-15 presents a summary of average CDD/CDF and CO emissions reported for each operating condition investigated in the parametric test. The temperature specified for each test condition is measured at the exit of the secondary combustion chamber. Each test condition consisted of two individual sampling runs, with the exception of the 1400°F condition, which

TABLE 3-14. EXISTING MODULAR EXCESS AIR COMBUSTORS

PLANT LOCATION	MANUFACTURER	# OF UNITS	INDIVIDUAL UNIT SIZE tpd	Mg/day	YEAR OF START-UP	APCD	ESP INLET TEMPERATURE °F	°C
Mayport Naval Station, FL	NA	1	48	44	1978	Cyclone	-	-
Pittsfield, MA	Vicon/Enercon	3	120	109	1981	EGB	-	-
Pascagoula, MS	Sigoure Freres	2	75	68	1985	ESP	NA	NA
Nottingham, NH	Combustall	1	8	7.3	1972	None	-	-
Cleburne, TX	Cadoux	3	38	35	1986	ESP	450	432
Bellingham, WA	NA	1	100	91	1986	NA	NA	
Rutland, VT	Vicon/Enercon	2	120	109	1987	ESP/ packed tower	400	204
Pigeon Point, DE	Vicon/Enercon	5	120	109	1987	ESP	400	204
Sitka, AK	Sigoure Freres	2	25	23	1985	Cyclone/ ESP	450	232
St. Croix, WI	Cadoux	3	38	35	1987	DS/FF	-	-
Pope County, MN	Cadoux	2	38	35	1987	ESP	415	213
Franklin, KY	Cadoux	2	38	35	1987	Cyclone	-	-
Lewisburg, TN	CICO	1	60	55	1980	WS/Cyclone	-	-
Frenchville, ME	Olivine	1	50	45	1982	None	-	-
Readsboro, VT	Combustall	1	NA	NA	1973	None	-	-
Stamford, VT	Combustall	1	10	9.1	1973	NA	NA	NA

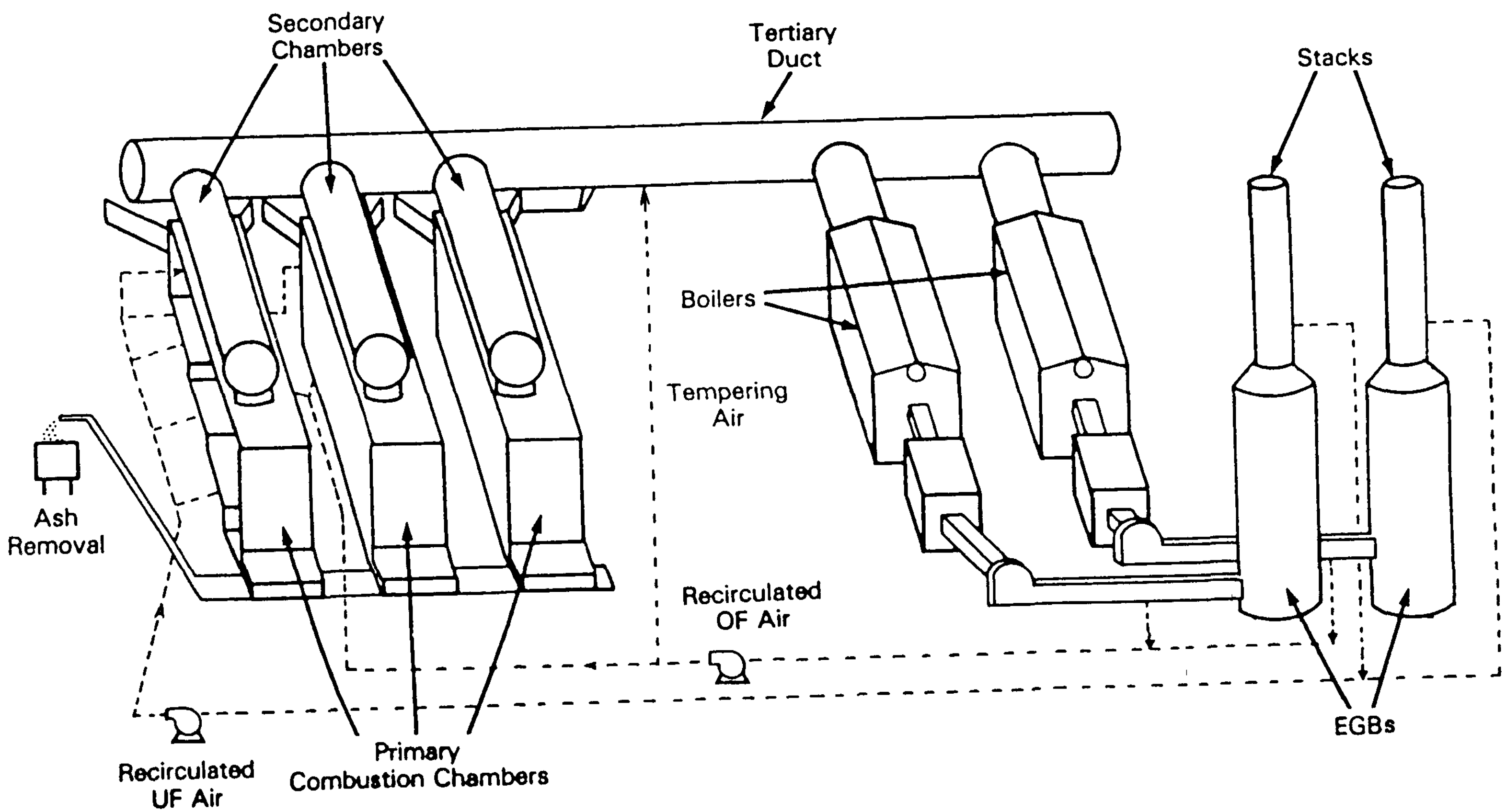

Figure 3-14. Pittsfield, MA Modular Excess Air MWC

TABLE 3-15. PITTSFIELD, MA MODULAR EXCESS AIR MWC EMISSIONS TEST DATA

TESTING CONDITION	TERTIARY DUCT		BOILER OUTLET		STACK
	CDD/CDF (ng/dscm)	CO (ppmv)	CDD/CDF (ng/dscm)	CO (ppmv)	CDD/CDF (ng/dscm)
1300°F - MSW	112	201	403	148	-
1400°F - MSW	18	44	40	22	-
1550°F - MSW	15	9	57	15	-
1550°F - MSW + H_2O	57	17	21	14	-
1800°F - MSW	-	4	94	12	154
1800°F - MSW, low O_2	76	7	165	9	-
1800°F - MSW + PVC	-	6	148	7	261
1800°F - PVC free	31	1	71	9	-
1800°F - PVC free + PVC	14	6	87	13	-
1800°F - PVC free + H_2O	48	8	28	7	-

included only one run. Sampling for CDD/CDF was performed at the boiler outlet for each operating condition. CDD/CDF stack sampling was performed during two conditions (1800°F-MSW and 1800°F-MSW and PVC), and CDD/CDF samples were gathered at the tertiary duct (just upstream of the boiler) during the eight other conditions. Carbon monoxide emission levels were measured in the tertiary duct and at the boiler outlet during all runs. Fairly extensive process monitoring was performed during this test program, including measurement of airflows and temperatures at various locations in the system. Testing was performed for the suspected precursors of CDD/CDF (PCBs, chlorobenzenes, chlorophenols). Continuous monitors were maintained to measure O_2, CO_2, CO, SO_2, NO_x, HCl, and THC at various locations in the system. Control of combustion temperatures was maintained by modulation of feed rates and recirculated flue gas and, to a lesser extent, fresh airflows.

One of the main conclusions made in the data analysis was that CDD/CDF emission levels were not generally affected by the different waste characteristics evaluated in the program. However, as expected, emissions of HCl were noticeably affected by PVC content in the waste. In most cases, CDD/CDF concentrations increased at each sampling location as the flue gases passed through the system. The temperatures at the tertiary duct sampling location are nearly equivalent to the target values specified in each sampling condition. The sampling point was upstream of the flue gas recirculation injection point (see Figure 3-14). The amount of recirculated (tempering) air injected into the tertiary duct controls the boiler inlet gas temperature, which varied from approximately 1100°F (593°C) during the 1300°F-MSW condition to approximately 1400°F (760°C) during normal operating conditions (1800°F-MSW). The average boiler outlet gas temperature varied from 460 to 540°F (255 to 282°C). Therefore, the flue gases pass through the critical CDD/CDF formation temperature, approximately 572°F (300°C), in the boiler. This is reflected by the increases in CDD/CDF concentrations between the tertiary and boiler outlet sampling locations. This result was observed during six of the eight conditions. The formation rate appears to be higher than actually may be occurring, because the gas stream at the boiler outlet location contains gases recirculated from ahead of the APCD. Increased concentrations of CDD were measured between the two sampling points during all but two conditions (1550°F-MSW + H_2O, and 1800°F-PVC free + H_2O). The influence of water on the CDD/CDF formation mechanism must be investigated further in order to draw conclusions related to this observation at Pittsfield. No PM sampling was performed during any of the test runs. However, waste moisture content may have reduced the amount of PM that was entrained in the fly ash and available for downstream catalytic reactions to occur. A normal sootblowing cycle was reportedly performed for the boiler during each 4-hour sampling run. The facility was reportedly scheduled for an annual maintenance shutdown 2 weeks after the completion of testing; the condition of the plant was considered normal during testing (no special maintenance was performed prior to initiating the program).

Paired runs gathered during normal operating conditions (1800°F-MSW) provided an average CDD/CDF emission rate of 94 ng/dscm at the boiler outlet (154 ng/dscm at the stack). At the 1500°F-MSW test condition, the total CDD/CDF emissions averaged 57 ng/dscm at the boiler outlet (no stack measurements available). As secondary chamber temperatures were decreased to 1300°F (704°C), the average CDD/CDF emission rate increased to 403 ng/dscm at the boiler outlet. The low temperature runs were performed for experimental purposes and are not expected to be encountered during normal operating conditions.

Stack testing was performed at Pittsfield during two operating conditions (1800°F-MSW, and 1800°F-MSW + PVC). Concentrations of CDD/CDF increased by 64 and 76 percent, respectively, from the boiler outlet location to the stack. Average boiler outlet gas temperatures ranged from 472 to 536°F (250 to 280°C) during these four sampling runs.

During all the aforementioned testing runs, CO emissions were measured, and average emission levels at the boiler outlet did not exceed 15 ppmv (4-hour average) except when operating at 1300°F (704°C), when 148 ppmv was measured.

The extensive emissions and process data generated at Pittsfield demonstrate that sufficiently high temperatures and adequate mixing conditions are present to minimize CDD/CDF and CO emissions at normal operating conditions. The low emission levels measured at Pittsfield confirm that the units have good combustion practices in place.

3.5.1.2 Pigeon Point, Delaware

A second data set available for the Vicon/Enercon facility is Pigeon Point, DE. This plant comprises five 120 tpd (109 Mg/day) units that fire a mixture of MSW and RDF, with ESP controls. The compliance test at Pigeon Point was conducted in two phases. Phase I consisted of HCl, SO_3, CO, and PM measurements made in the stack. Particulate testing was also performed at the ESP inlet location for all four units. Phase II involved stack sampling for CDD/CDF and heavy metals (Pb, Hg, Be, Ni, As, Cd, Cr).

The three run average uncontrolled PM levels for each of the four flues tested were 1.03 gr/dscf (2370 mg/dscm), 1.03 gr/dscf (2370 mg/dscm), 0.90 gr/dscf (2070 mg/dscm), and 0.43 gr/dscf (990 mg/dscm).[39] One of the flues discharges gases from two combustors. Average flue gas temperatures entering the ESP ranged from 393 to 433°F (200 to 223°C). Due to the low particulate concentrations and the low operating temperature, it is doubtful that substantial CDD/CDF formation would occur in the ESP.

Three CDD/CDF sampling runs were performed in the stack of unit #2. The average emissions were reported to be 105 ng/dscm.[39] The average stack temperature was reported to be 374°F (190°C). The CO data included in this test was measured by ORSAT analysis and was reported to be 0.0 percent by volume. The CDD/CDF concentrations in the ESP fly ash are also reported for each sampling run. Very limited process data are available to use in characterizing the operation of the Pigeon Point facility during testing. The plant attempts to feed a mixture of 5 pounds RDF per pound of MSW (5 kg RDF per kg MSW), and it appears that this ratio was maintained during the tests. Based on the assumption that the combustor design and operation are similar to that at Pittsfield, it can be concluded that good combustion practices are in place at Pigeon Point. The measured emission levels from Pigeon Point and Pittsfield confirm the good performance of the Vicon/Enercon design. The consistency of the CDD/CDF data with that measured at Pittsfield also indicates that CDD/CDF emission levels are more dependent on combustion technology than differences in waste feed characteristics at the two sites.

3.5.1.3 Alexandria, Minnesota

A third data set is available from a facility using the Cadoux design. Emissions testing was performed at the Pope/Douglas Waste-to-Energy Facility in Alexandria, MN in July 1987. This plant began operating in May 1987 using two 38 tpd (35 Mg/day) Cadoux modular excess air combustors. Both units are equipped with an ESP. Average CDD/CDF emissions at the stack were reported to be 446 ng/dscm.[40] The continuous monitoring results indicated that average CO emissions were 24 ppmv (1-hour average). The average flue gas temperature at the ESP inlet sampling location ranged from 490 to 503°F (254 to 262°C). These values are in the temperature window where CDD/CDF formation has been observed. Therefore, it is assumed that CDD/CDF at the ESP inlet was lower than the concentrations in the stack. The CDD/CDF and CO measurements were made on Unit #2. Particulate sampling was also performed in the stack of both units.

Thermocouples were installed in Unit #1 at two locations in the primary combustion chamber. The first was located on the side wall at the grate level, and the second was in the top of the chamber. The average temperature at the grate varied from 1300 to 1650°F (704 to 899°C) and the temperature in the upper furnace ranged from 1770 to 1990°F (965 to 1088°C). Charge rates were measured during the testing program and both units were operating between 100 and 145 percent rated capacity. Oxygen levels were also measured in an eight-point traverse at the combustor outlet, and average concentrations were 14.8 percent at Unit #1 and 12.8 percent at Unit #2. These values equate to approximately 245 percent and 160 percent excess air, respectively.

3.5.2 Baseline Emissions Estimates

Baseline emissions for the model plant are established using the two Vicon/Enercon MWCs at Pittsfield and Pigeon Point. The emissions data from these systems and the Cadoux facility at Pope/Douglas County are plotted together in Figure 3-15. The off-spec, low-temperature runs from the Pittsfield parametric study are not included in the baseline determination. Baseline emissions are assumed to be 200 ng/dscm CDD/CDF and 50 ppmv CO. APCD inlet PM emissions are assumed to be 2 gr/dscf, which is an average value for mass burn systems.

3.5.3 Combustion Modifications

The model plant was judged to have all the necessary features of good combustion practice. Therefore, no combustion modifications were required.

3.6 O'Connor Rotary Waterwall MWCs

As shown in Table 3-16, there are three existing MWCs using the O'Connor Rotary Waterwall design. The Gallatin, TN plant commenced operation in

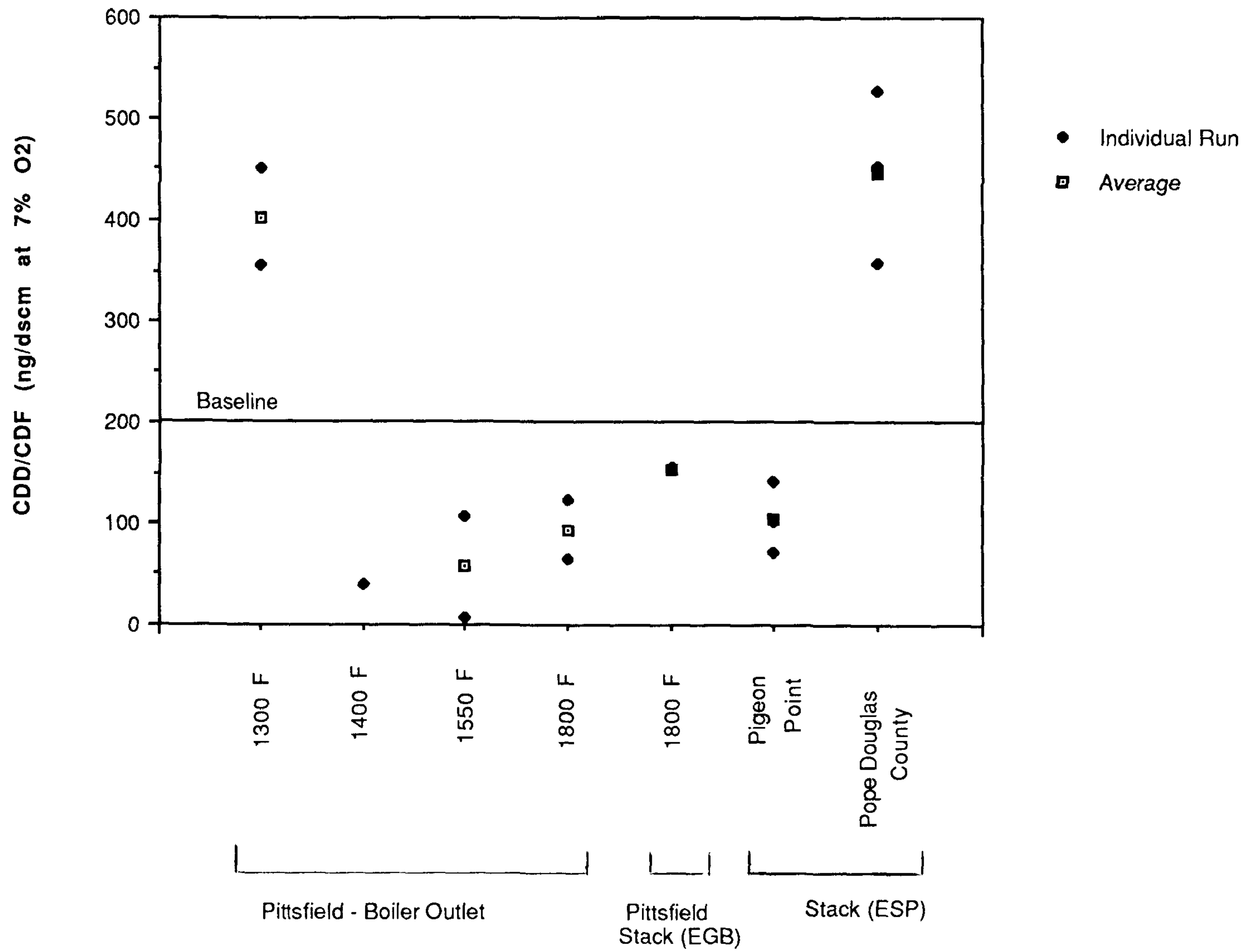

Figure 3-15. Mass Burn Modular Excess Air Baseline Determination

TABLE 3-16. EXISTING ROTARY WATERWALL COMBUSTORS

Plant location	Gallatin, TN	Bay County, FL	Dutchess County, NY
Stoker manufacturer	O'Connor	O'Connor	O'Connor
Boiler manufacturer	Keeler	Deltak	Deltak
Number of units	2	2	2
Unit size (tpd)	100	255	253
Unit size (Mg/day)	91	232	230
Year of start-up	1981/82	1987	1987
APCD	Cyclone/ESP	ESP	Cyclone/DI/FF
ESP inlet temperature (°F)	390	400	-
(°C)	199	204	-

December 1981 using two 100 tpd (91 Mg/day) combustors. Gallatin was originally equipped with a cyclone and an electrostatically enhanced baghouse, but the fabric filter collector, which experienced numerous operating problems, was replaced by an ESP in 1983. Westinghouse purchased O'Connor in 1986, and started up the Bay County, FL plant in 1987. Bay County comprises two combustors, each with a rated capacity of 255 tpd (232 Mg/day). Wood waste is currently co-fired with MSW at Bay County. Electrostatic precipitators are used for emission control. A third O'Connor plant located in Dutchess County, NY, commenced operation in 1987, using two 253 tpd (230 Mg/day) combustors equipped with a cyclone, dry sorbent injection, and a baghouse.

3.6.1 Emissions Data

There are currently no published data available to estimate baseline CDD/CDF emission levels. Testing has been performed at Bay County, but results have not yet been published. Some limited test data are reported for the Gallatin plant and for an O'Connor facility in Kure, Japan. Particulate emissions at the APCD inlet were reported to be 3.08 gr/dscf (7080 mg/dscm) and 2.36 gr/dscf (5430 mg/dscm), respectively, from these two plants.[23] In addition, CO data were gathered at Gallatin and the average emissions were reported to be 545 ppmv. In a meeting with EPA, Westinghouse reported that the Bay County plant has been able to achieve CO emissions less than 100 ppmv as a result of recent modifications made to combustion air distributions.[41]

3.6.2 Baseline Emissions Estimates

Table 3-17 presents an assessment of the performance of the Bay County MWC relative to recommended good combustion practices for rotary waterwall combustors. An engineering evaluation of the facility design led to conclusions that the existing tertiary (overfire) air nozzles above the discharge of the rotary section do not provide sufficient penetration and coverage of the boiler cross section. As a result, mixing of combustion products with oxygen is not optimized and CDD/CDF emissions are estimated to be relatively high. Due to a lack of available data to establish a CDD/CDF emission value, it was assumed that the emission levels were similar to those of the small mass burn waterwall model plant and the RDF fired model plants. The baseline CDD/CDF emissions were assumed to be 2000 ng/dscm. Based on information provided by Westinghouse, there is evidence that 100 ppmv CO can

TABLE 3-17. MASS BURN ROTARY WATERWALL MWCS - PERFORMANCE ASSESSMENT

FACILITY	Bay County, FL
NUMBER OF UNITS - FGC	2 - ESP
UNIT SIZE, tpd (Mg/day)	255 (232)
<u>UNCONTROLLED EMISSIONS</u>	
CDD/CDF (ng/dscm)	Not Available (NA)
CO (ppmv)	--
PM (mg/dscm)	NA
<u>CONTROLLED EMISSIONS</u>	
CDD/CDF (ng/dscm)	NA
CO (ppmv)	<100

COMBUSTION PARAMETERS	GOOD COMBUSTION PRACTICE RECOMMENDATIONS	FACILITY DESIGN AND OPERATING CONDITIONS
<u>DESIGN</u>		
Temperature at fully mixed location	1800°F (982°C) average	1400°F (760°C) at inlet to convective section
Underfire air	4 plenums, including one at burnout grate	4 plenums (one at afterburning grate)
Overfire air capacity	Sum of secondary and tertiary air designed to supply 40% of total air	Confidential
Tertiary air design	Complete coverage and penetration	Confidential
Auxiliary fuel capacity	As required to achieve temperature limits during start-up	Oil - 40% load
Exit gas temperature	<450°F (232°C) at PM control device inlet	450°F (232°C)
<u>OPERATION</u>		
Excess air	3-9% O2 in flue gas (dry)	5-57% O2 (wet)
Turndown	80-110% design load	30% minimum
Tertiary air	Complete coverage and penetration	Not achieved
Start-up procedures	Auxiliary fuel to design temperature	Use steam preheat from adjacent combustor
Auxiliary fuel use	High CO, low temp; start-up/shutdown	NA
<u>VERIFICATION</u>		
O2 levels	Monitor	Yes
CO	Monitor (<100 ppm at 7% O2)	Yes
Temperature	Monitor	Yes
Air distribution	Monitor	UF, OF, tertiary
Exit gas temperature	Monitor	Yes

be achieved. Therefore, this value is assumed as a baseline emission level. Lastly, it was assumed that inlet particulate emission levels are typical of mass burn waterwall MWCs. Therefore, 2 gr/dscf (4600 mg/dscm) was assumed as a baseline value.

3.6.3 Emission Reductions Resulting From Combustion Modifications

The only modification made to the model plant is a redesign of the tertiary (overfire) air nozzles to improve mixing. Estimated emission reductions result in CDD/CDF emissions of 400 ng/dscm. The basis for this estimate is engineering judgment. No reduction in CO or PM emissions is assumed.

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16. ABSTRACT

The EPA's Office of Air Quality Planning and Standards (OAQPS) is developing emission standards and guidelines for new and existing MWCs under the authority of sections 111(b) and 111(d) of the Clean Air Act (CAA). The EPA's Office of Research and Development (ORD) is responsible for developing the technical basis for good combustion practice (GCP), which is included as a regulatory alternative in the standards and guidelines. This report provides the supporting data and rationale used to establish baseline emission levels for model plants that represent portions of the existing population of MWCs. The baseline emissions were developed using the existing MWC data base, or, in cases where no data existed, engineering judgement. The baseline emissions represent performance levels against which the effectiveness and costs of emission control alternatives can be evaluated. An assessment of potential combustion retrofit options was developed and applied to each model plant, and emission reduction estimates were made for each retrofit application. This report provides the rationale used to estimate the emission reductions associated with each combustion retrofit.

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